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SIMULATION AND EVALUATION OF AMBULANCE SYSTEMS

A THESIS

Presented to

The Faculty of the Graduate Division

by

Raymond D. Wilmot

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SUMMARY

Each year accidents account for thousands of deaths and serious injuries in the large cities of the United States. Many lives can be saved and countless permanent injuries avoided by providing faster, more effective ambulance service. Helicopters are presently being considered by several metropolitan areas as a means of improving their existing ambulance capability. The helicopter's ability to rapidly fly above the congestion that often accompanies accidents is a strong supporting factor for its use in evacuating victims.

The objective of this research is to develop and test a simulation model to be used in the analysis of metropolitan ambulance systems utilizing various combinations of vehicles. The vehicle types include ambulances, dual purpose vehicles and helicopters. Pertinent factors considered in the model are weather, accident rate, locations of accidents, hospitals and vehicles, and vehicle maintenance scheduling.

In the general, the behavior of the simulation produced no significant reason for rejection of the model as an acceptable representation of an ambulance system.

CHAPTER I

INTRODUCTION

Objective

The objective of this research is to develop and test a simulation model to be used in the analysis of a metropolitan ambulance system utilizing various combinations of vehicles. These vehicles include conventional ambulances, helicopters and emergency vehicles, such as dual purpose vehicles, used by police and fire departments which are capable of transporting patients to nearby medical facilities. Pertinent factors considered include weather, accident rates by time of day and year, locations of accidents, hospitals and vehicles, and vehicle maintenance scheduling.

Problem Definition

The methods presently being used to transport the injured and critically ill of our cities lag far behind modern technology. There have been no appreciable changes in the mode of transporting these patients for over 50 years. During the last 20 years the armed services have made extensive use of helicopters for evacuating battle casualties and transporting them to medical aid stations and hospitals. As more people become aware of the usefulness of the helicopter in this life-saving role, the question is frequently asked as to why helicopters are not used for civilian casualties.

Helicopters do provide a promising solution for many civilian casualty evacuations. There is not, however, a direct extrapolation from the use of helicopters for battlefield evacuations to the use of this versatile aircraft for civilian use. The conditions of combat make the use of surface vehicles very slow and unreliable. Roads may be nonexistent, and merely transporting the patient on the ground might compound his injuries. On the other hand, the helicopter crews subject themselves and their helicopters to high risks and often unorthodox maneuvers that would not be acceptable in a densely populated area. No decision must be made on the battlefield as to the type of vehicle best suited for the evacuation, and cost plays nearly a nonexistent role in the dispatching of a helicopter.

There are very few civilian ambulance systems that are financially able and authorized to make large expenditures for new equipment without first giving sound justification for the equipment. In discussing the use of helicopters with hospital and ambulance officials, as it was obvious that most were greatly interested in the idea and could see definite advantages to having helicopters as a supplement to their existing service. At the same time, their experience helped them to find problems that might arise from the use of helicopters. Such factors as cost, personnel, weather, heliports, proper utilization, maintenance, equipment, public acceptance, time saved and effect of time saved must be given special consideration. Only after an extensive evaluation of these factors could a director be in a position to request and substantiate the use of any combination of vehicles, whether or not that combination includes helicopters.

Importance of Study

The general public is aware of the heavy traffic on streets and highways. Experienced drivers may also realize that, although highways are continually being improved, delays caused by accidents are becoming more frequent. Although these delays may seem only an annoyance to most people, they may mean sustained pain, permanent injuries or even death to accident victims. In cases involving coronaries, hemorrhaging, head injuries, and in some cases shock, a few minutes can have a great influence on the ultimate outcome of the patient's initial condition.

From a strictly humanitarian standpoint, helicopters should be included in every metropolitan emergency transportation system, assigned to hospitals, police or fire departments, or be provided by an independent organization. If viewed strictly from an economic standpoint, a city could run an ambulance for a year for as little as $20,000 (2) while a helicopter would cost about $80,000 per year (4). A private ambulance service in Wyandotte, Michigan, charges $25.00 plus $1.00 per mile for an ambulance and $30.00 plus $1.50 per mile for its helicopter (13). Since many ambulance services presently work at a loss each year, it might prove necessary to find new means of financing a more expensive system incorporating helicopters.

Both the humanitarian aspects and the financial problems are essential elements that must be investigated before a community embarks on a major change in its ambulance service; however the emphasis of this research is on the effects of different combinations of vehicles on service time. To be evaluated are:

1. Change in mean service time where service time is defined as the total time between a call for a vehicle and the patient's arrival at a hospital.

2. Shift in the distribution of service times.

3. Effects of different combinations of vehicles.

4. Effects of more than one hospital on vehicle utilization.

5. Effects on the system of future increases in emergency calls.

Furnished with this information, the decision makers with the medical care responsibility for a metropolitan area will be in a better position to make a sound evaluation of their vehicle requirements.

Scope

It is the intent of this thesis to present a valid simulation model for the future evaluation of metropolitan ambulance services and the effects of adding helicopters to these services. The validation of the model is accomplished by comparing its output with data obtained in the area being simulated. In this research, Grady Memorial Hospital of Atlanta, Georgia, was the source of data which consisted of ambulance calls by time of day and duration, ambulance scheduling, accident type and accident location. The validation period is the year 1968 and the bases of validation are accident rate, mean time of service and distribution of service times.

The model is to simulate the effects of weather on accident rates, ambulance service time and helicopter effectiveness (consisting of patient service time and flying feasibility). The model must also simulate vehicle scheduling since the number of vehicles and crews varies by time of day. Finally, the model is to show the results of the interplay of distinct and different ambulance systems working together to service all emergency calls.

Assumptions

The computer language chosen for this research, the General Purpose System Simulator II (GPSS II), allows many parameters of the problem under study to be taken into account. For this reason, the assumptions can be minimized. Some decisions, however, had to be made and they are presented here, not necessarily in the order of their importance.

Accident Interval

As will be explained later under Method of Approach, the interval between accidents is a random variable which is a function of time of day and weather.

The time between arrivals for calls received by Grady Memorial Hospital form a negative exponential distribution and it is assumed that other ambulance services would have similar patterns.

Accident Location

The distances from the scenes of accidents to the nearest emergency medical facility are considered to be exponentially distributed about a mean of three miles. This value can be changed at the discretion of the investigator. The procedure is included in Appendix B of this thesis.

Accident Types

Accidents are considered to fall into one of three types. The first type, denoted Mode I, are accidents which occur on freeways where there is enough open space for a helicopter to land with little danger of hitting electrical wires, poles, towers, buildings, or other surface obstructions. Also included are pickups from selected points where landing is possible.

Mode II accidents consist of accidents where time is important to the well-being of the victim, but it is the decision of the dispatcher that an ambulance from the closest hospital or private company can match the time of a helicopter.

Mode III accidents encompass accidents where time is not a critical factor to the person requiring the service and those cases where the use of a helicopter is deemed impractical. Examples of the first of these two conditions would be taking patients from a hospital to their homes and transporting invalids from one point to another. Examples of the second condition are: servicing a call where obstructions might make flying dangerous; having no landing sites close to the accident site; and having a patient who refuses to fly.

Method of Approach

The Problem

A recent television editorial (5) stated that it was not uncommon for a victim to wait more than 30 minutes for an ambulance if he is in the city. Suburban victims usually must wait considerably longer.

The editorial continued that helicopters could do much to reduce this time.

A literature search indicated great interest in the possible use of helicopters for civil use, and an occasional article pertained to the use of helicopters on mercy flights. The United States Coast Guard, of course, has been using helicopters for over 20 years, and it has documented many instances where helicopters provided fast effective service in rescue work. Very little has been done in evaluating existing ambulance systems and nothing was found on the analysis of an integrated ambulance/helicopter system with the exception of a trial program sponsored by the Department of Transportation in the Philadelphia, Pennsylvania, metropolitan area. In this case helicopters were assigned to the police and used for the combined function of traffic control and emergency evacuation.

An evaluation of the hospital and ambulance interface indicated the characteristics which required incorporation into the system model. Briefly, these are:

1. Location of emergency medical and ambulance facilities.
2. Hours of operation of emergency medical facilities.
3. Crew scheduling for ambulances.
4. Accident rate by time of day and weather condition.
5. Accident location distribution.
6. Ambulance effectiveness by time of day and weather conditions.
7. Helicopter effectiveness by time of day and weather conditions.

8. Helicopter operating characteristics.

9. Proposed helicopter base location.

The Simulation

The system for one hospital with its own ambulance service is illustrated in Figure 1. If the hospital's ambulances are busy, a call is made to a private company to service overflow calls, thus eliminating any backlog of patients waiting for service.

The three major components of the system, the Accident Generator, the Hospital and the Vehicle Service, are the building blocks for simulating a metropolitan ambulance system. Each geographical area about an emergency medical center has a variable rate of accidents. Each emergency medical center has specific hours of operation which may not be 24 hours each day. Each ambulance service (air or ground) has crew scheduling which may change the number of available vehicles at different times of the day.

All of these characteristics can be handled by the General Purpose Systems Simulation II (GPSS II) language selected for use here. This language allows the investigator the freedom and ease to change the model to become more, or less, complex by changing the parameters or the accuracy of the component relationship functions. As an example of this, weather can be introduced into the model as a constant or it can be considered as a complex function which will provide various system effects with the changing of time.

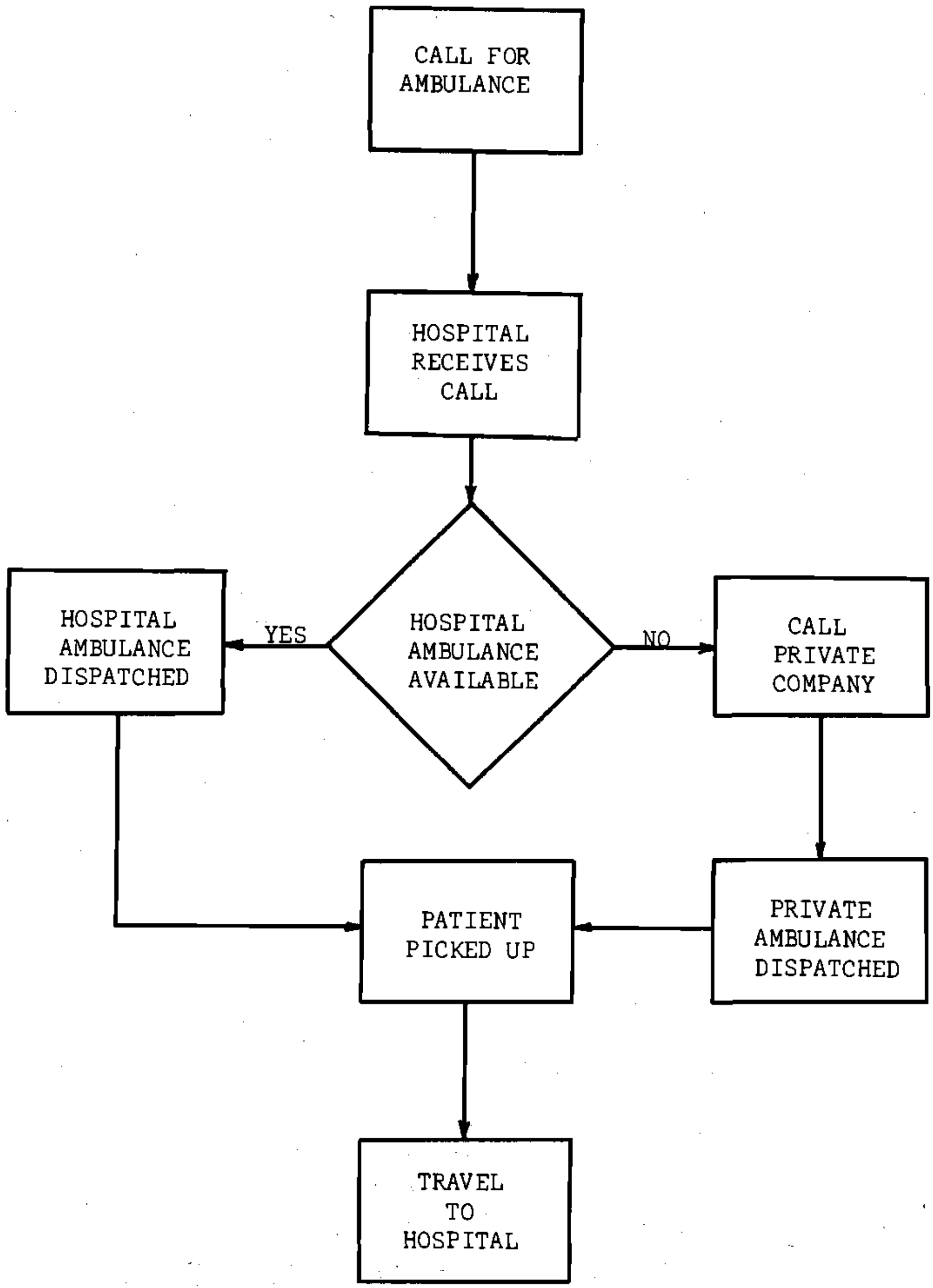


Figure 1. Ambulance Service Procedure

Validity of the Model

The validity of the service time distribution and the validity of the time between calls distribution of the model was determined by use of the Kolmogorov-Smirnov Test for goodness of fit (3,18). The primary measure of validity was the distribution of service times for an ambulance system composed of surface ambulances. The distribution of time between accidents was also compared with statistical data of the simulated area.

The Kolmogorov-Smirnov test was developed for use with ranked serial data. It has been determined that the test can also be used with grouped data with little change in the appropriate significance levels where large sample sizes are involved (11). The sample sizes for this research were 900 for service times and 678 for the time between accidents.

CHAPTER II

LITERATURE SURVEY

Ambulances

It is generally accepted that ambulances first received widespread use during the Crimean War (1853-1856). These first vehicles were horse-drawn surgical carts which were taken onto the battlefield. Whatever treatment the wounded required was administered where they lay by surgeons who accompanied the carts. The carts were designed by a French surgeon, Dominique J. Larrey (14), and provided the field physician the equipment necessary for prompt care of the injured. It is interesting and significant to note that the ambulance was first developed to fill a military requirement.

The development of ambulances to their present state closely parallels the development of the automobile. The use of machine power has made it possible for a vehicle to transport a patient to a medical facility; and this has not only resulted in a more sanitary environment in which to treat the patient, but it also provides better utilization of medical personnel.

During World War I, the ambulance was strictly a means of transporting the wounded, and virtually no first aid was administered by the ambulance crew. By World War II, although ambulances had not changed appreciably, soldiers were receiving first aid training and ambulance crews were better trained in first aid procedures that could be performed enroute to the hospitals.

Today, the military makes extensive use of helicopters in the evacuation of battlefield casualties. Emergency transportation of civilian casualties is provided by a conglomeration of ambulances run by hospitals, private companies and funeral homes, and in some communities, dual purpose light trucks or stationwagons are operated by police or fire departments, or volunteers.

Communities, including Fairfax, Virginia, Charlotte, North Carolina, and Atlanta, Georgia, use light duty emergency vehicles as a supplement to established ambulance services (14). These vehicles are less expensive than ambulances and sacrifice very little in patient comfort.

The problems associated with retaining qualified personnel in industry are shared by ambulance services. Low wages and peculiar shift work often discourage responsible, well-trained drivers and attendants, resulting in many ambulances having crews with little or no medical training or related experience.

Many funeral homes have traditionally maintained an ambulance practice as a community service but few are able to make enough to pay expenses and, consequently, several desire to terminate this activity (14). Their withdrawal is adding to the need for a more effective ambulance system.

The American College of Surgeons has been aware of the problems of patient transportation for some time and in August, 1966, issued the final form of *A Model Ordinance Regulating Ambulance Service* (1). This is a recommended model, or guide for standardizing the quality of ambulance service in regard to license standards, equipment, personnel, and reports. States, counties and cities are being encouraged to use this model in drafting their own ordinances for ambulance service.

Even as the nation is becoming aware of the need for a higher quality ambulance service, increasing traffic congestion on highways is retarding the utility of surface ambulances. The seriousness of the problem is illustrated by the ambulance service of Grady Memorial Hospital in Atlanta, Georgia. In the years 1966, 1967, 1968, Grady Hospital answered 15,180, 18,810 and 22,394 calls, respectively (17). Of these, approximately 20 per cent were caused by traffic accidents. Ambulances will continue to fill an important role in transporting the sick and injured to emergency medical facilities; however, the continual updating of this service is mandatory. A study is under way in New York to assign the city's ambulances to "ambulance stands" (8) positioned at strategic points throughout the city, thus reducing the over-all distance an ambulance must travel in servicing a patient.

Dual Purpose Vehicles

Earlier, it was stated that many funeral homes want to terminate ambulance service because it is not profitable. It requires effective management, and a responsible clientele, for any ambulance service to be self supporting. All too often patients cannot or will not pay for ambulance service.

In an effort to supplement existing ambulance services, and provide help to communities not having ambulance service, many state, county, and city officials have recommended the utilization of dual-purpose vehicles. These vehicles are often assigned to police and fire departments and are used on a selective basis where it is suspected that an ambulance might be needed. In a review of traffic accidents which occurred in and around Atlanta, Georgia, it was noted that a substantial number of patients were transported to the hospital by the police department. This service is excellent for delivering those patients who require medical treatment but have nonserious injuries.

It is seldom that any one type of equipment can perform a dual role and do both tasks with complete satisfaction. The dual-purpose vehicle is no exception. Its design allows it to be a good back-up vehicle, but it does not provide the smooth ride of an ambulance nor is it always ready in case of an emergency.

Helicopters

The use of helicopters for medical assistance can be traced back to January 3, 1944. On that day, at Sandy Hook, New Jersey, an explosion and fire swept a United States Navy destroyer which was being loaded with ammunition. Dozens of men were killed or injured. Commander Frank A. Erickson took off within minutes from the Coast Guard Air Station at Brooklyn, New York, in an early model Sikorsky helicopter. Carrying cases of plasma and medical supplies, he flew through bad weather but was able to deliver his cargo which proved instrumental in saving many lives (6).

The helicopter has become the main Search and Rescue (SAR) vehicle of the United States Coast Guard. Its ability to penetrate into otherwise inaccessible areas and to hover above an accident site led the way to the Coast Guard's decision to phase out large seaplanes and many of the coastal lifeboat stations as well.

During the Korean War (1950-1953) the helicopter became a vital tool in the lifesaving of thousands of American servicemen who were wounded. In all, over 20,000 serious casualties were transported by helicopter during that war (6). An important statistic from that war is the mortality rate of 2.5 per cent compared with a rate of 4.5 per cent in World War II. The mortality rate in the Vietnam War is expected to be lower than 2 per cent. In 1966, the Army Medical Service operated 61 helicopters and accomplished 43,058 evacuations, airlifting 64,488 patients in Vietnam.

In mid-1968, there were 38 cities and governmental agencies in the United States using helicopters for diverse purposes (4). These included: law enforcement, traffic control, riot control, search and rescue, city planning, aerial photography, ambulance service, fire fighting and VIP transportation.

The first private ambulance service to provide helicopter transportation is Superior Ambulance Service of Wyandotte, Michigan. The helicopter, a Bell 47J, made a trip from Wyandotte to Dayton, Ohio, a distance of 200 miles, and then returned to Ann Arbor, Michigan, with a brain tumor patient. The total flying time, including a fuel stop, was little more than three hours, a savings of about 90 minutes over conventional ambulance transportation time (13).

Chicago has helicopters assigned to its fire department, while New York City and Los Angeles have them assigned to their police departments. Recently, when Chicago was snowed in, the use of helicopters provided the only means of rapid evacuation of patients.

A study, sponsored by the Department of Transportation, began in November, 1967, in Pennsylvania. This study involved the state's Highway Department, Police Department, Department of Health, Aeronautics Commission, and the National Highway Safety Bureau of the Department of Transportation. The first phase of the study consisted of operating helicopter patrols about three hours daily and providing a stand-by service from 7 A.M. until 9 P.M. each day to try to determine helicopter capabilities in a civil environment with regard to medical evacuation. The second phase moved the service from the phase one site of Greater Philadelphia to Chester County to provide a rural environment under which to continue the study (7).

Another aspect of helicopter utilization in medical assistance was demonstrated by Dr. Hans-Werner Feder of West Germany (6). Using funds acquired through donations Dr. Feder hired a helicopter and pilot and spent his vacation, from August 11 to September 1, 1967, responding to 52 police calls for ambulances. The two-seater helicopter had a 180-horsepower aircooled engine and could be airborne after a 40-second warm-up. It was the purpose of the flights to get medical attention to the injured at the accident site. Dr. Feder attributes at least one life saved to this test.

Some interesting facts came from Dr. Feder's study. In 13 cases ambulances were on the scene before his helicopter arrived. In five cases a rescue car appeared as he arrived. In 18 cases, up to 30 minutes had elapsed after his arrival before an ambulance arrived. In two cases, no ambulance was required. Police arrived before the helicopter 32 times, arrived simultaneously with the helicopter twice and arrived after the helicopter four times. This may be attributed to the large number of police vehicles which cruise the streets and highways. The effect of this would be that the police in most cases could direct traffic, thus providing for safer operation of the helicopter on landing and take-off.

The present cost of purchasing and operating helicopters is a vital deterrent to a greater user growth rate. A helicopter large enough to handle two stretcher patients and a two-man crew would initially cost from $95,000 to $120,000 (4). A possible solution to obtaining more helicopters at lower cost for ambulance service lies in the eventual surplus of military helicopters at the conclusion of hostilities in Vietnam. If these helicopters are serviceable and can be loaned, given or sold (at less than market value) to civil governments or responsible organizations, a widespread usage may be possible.

Emergency Medical Facilities

A trend of certain hospitals is to become community medical centers. About half of the general hospitals in the United States have outpatient departments which are frequently organized around specialty clinics and are limited in providing continuous and uniform care.

Few hospitals maintain a complete emergency staff around the clock. In some cases, no doctor is at the hospital at all times during the night (15). For these reasons, and various others of similar importance, most metropolitan areas have a varying level of emergency medical capability with only a few facilities offering continuous complete service.

Integrated Emergency System

The combination of ambulances, dual purpose vehicles, helicopters and emergency medical facilities requires close cooperation and coordination to form a good integrated system. A central coordinator would result in time saved, fewer duplications of ambulances sent to accident sites, and the dispatching of the best-suited vehicle. The vehicle could also be directed to the closest hospital capable at the time of providing the necessary aid.

Transportation Modeling

The literature pertaining to patient transportation indicates that little has been done toward modeling ambulance systems. Only recently has the nation taken a noticeable interest in upgrading ambulance service. This plus a lack of funds are probably the attributable factors for the lack of research. The National Highway Safety Bureau of the United States Department of Transportation is making funds available to cities and states in an effort to upgrade emergency transportation systems by studies and test projects, and by supplementing local funds for the purchase of equipment.

CHAPTER III

SYSTEM CHARACTERISTICS

The system to be simulated in this research is composed of ambulances, helicopters, hospitals and patients. This is a transportation problem where patients at various places require transportation to other locations, using one of the vehicles in the system. To complicate the problem, the distance to be travelled may change from one patient to the next; weather conditions or maintenance may limit the usefulness of a mode of transportation; scheduling of crews dictates the number of vehicles in service at any given time; and finally, the number of patients may fluctuate from one hour to the next or with a change in the weather. This chapter presents the interaction between these complex components and the rationale used in constructing a computer model to simulate the system.

For the purpose of simulation, dual-purpose vehicles and ambulances will be called ambulances. They both have room for two stretcher patients and are equally affected by weather and traffic. All vehicles have a minimum time of service dictated by the type vehicle and the characteristics of the area in which they operate. To this minimum time must be added any delays caused by the driver, traffic, weather and patient readiness.

Traffic is mainly a function of the time of day. During the rush hours, streets may become heavily congested, making progress considerably slower for an ambulance. Unfortunately, the occurrence of most accidents is also the time of most traffic. Home accidents also increase as do the number of injuries associated with arguments and alcoholic consumption. The late afternoon and evening are the most demanding on the ambulance service. Figure 2 shows the distribution of calls answered by Grady Memorial Hospital in 1968.

The effect of weather on traffic accidents is greatest immediately following an adverse change in the weather. Drivers must adjust to the surface condition of the road and to any change in visibility. If a road becomes wet, the immediate condition is a very slick surface brought about by the water and dirt on the surface. As more water wets the surface the dirt is washed away, thus providing a slightly improved, but still hazardous, condition. Ambulance response is not severely hampered except by the most adverse weather, such as heavy dust, fog, rain and snow, where visibility is greatly reduced. Where ice and snow are common, provisions are made to reduce the effect by equipping the vehicles with either snow tires or chains. Seldom is an ambulance completely stopped because of weather, but this can happen in snow storms or very heavy fog. Since the chance of all ambulances being stopped is extremely small, this peculiar case will be omitted from the system.

The readiness of the patient upon ambulance arrival was studied in the Boston metropolitan area (20) and the results of that study will be used for predicting patient delay in this research. A summary of pertinent results from that study is included in Appendix A. No other information source of this type could be found.

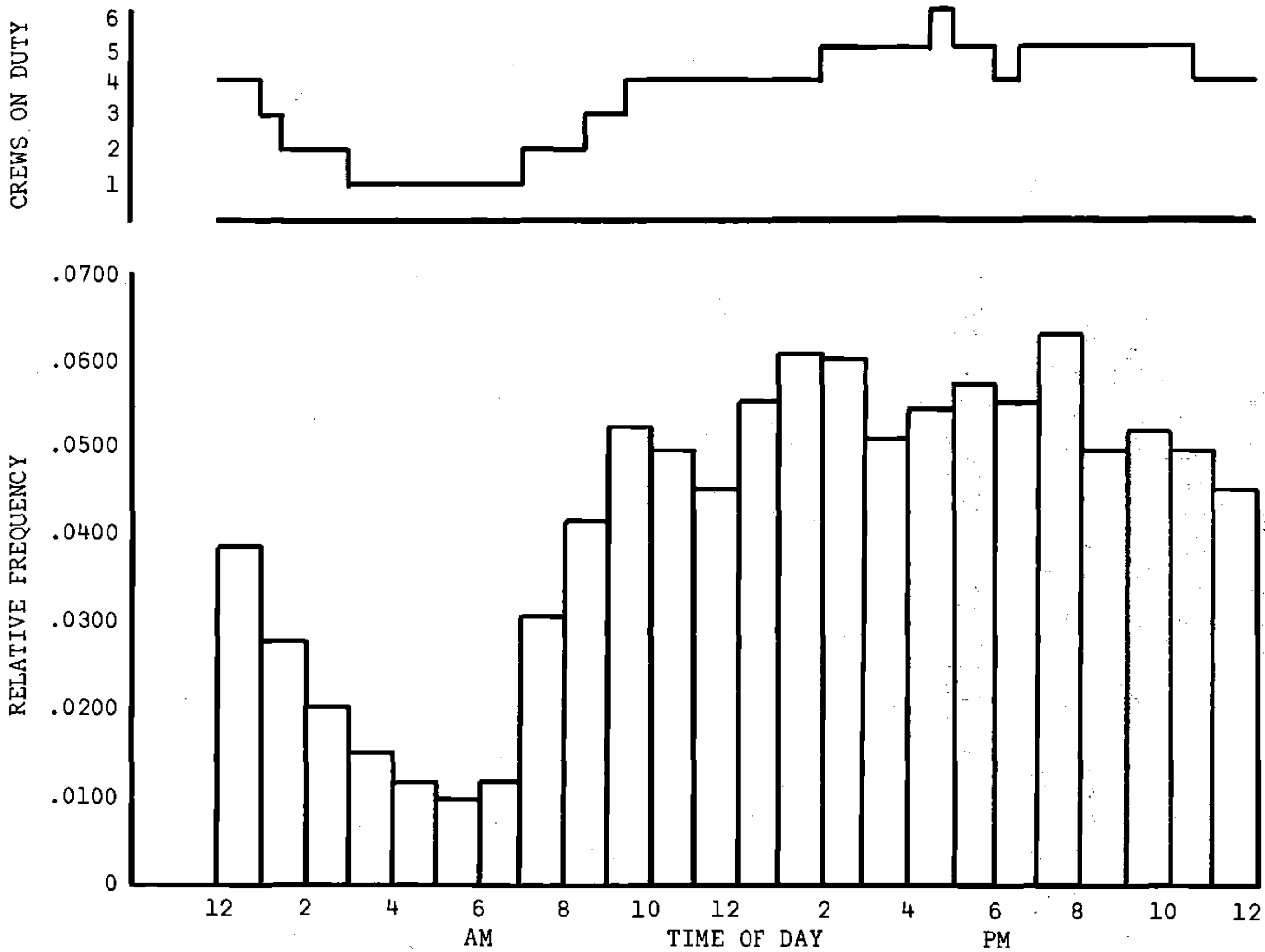


Figure 2. Ambulance Crews Scheduled and Occurrence of Accidents
[Data obtained from Grady Memorial Hospital's 1968 Records]

Drivers differ in their ability to maneuver in traffic and in their evaluation of the necessity for speed. Since the differences in drivers are not intended to be a part of this study, these differences will be considered only as an indistinguishable part of the variation in service time.

In the normal operation of surface vehicles, a certain number of vehicles is assigned to a base location with a dispatcher to monitor calls. In a metropolitan area, some ambulance units may be assigned to one or more hospitals, while others are run by profit-making companies or volunteers. The dual-purpose vehicles may also be operated by volunteers, police or fire departments. For the system, these ambulance bases are defined as points within the area from which surface vehicles are dispatched and to which the vehicles return at the completion of their calls. These points may be positioned at hospitals or other locations throughout the area.

Helicopters are presently being produced and advertised for use in evacuating patients. The helicopter characteristics assumed for this study are easily attainable by commercially-available helicopters. These characteristics are:

1. Carry a crew consisting of a pilot and a medic.

2. Carry two stretcher patients internally.

3. Afford room for the medic to attend the patients.

4. Carry at least the minimum recommended emergency equipment as suggested by the American College of Surgeons (1).

5. Cruise at a minimum speed of 100 miles per hour.

6. Be small enough to land and take off from expressways.

An average rotor diameter for helicopters having these characteristics is about 34 feet, and the distance above the ground for the horizontal rotor is eight to ten feet. It is assumed that helicopters can service nearly all freeway accidents and can provide a pickup service to selected sites throughout a metropolitan area.

Helicopter operations are also hampered by bad weather. Good visibility is essential to low-level operation and landing. Navigation in bad weather can be accomplished by use of VHF, UHF, or if necessary, HF radios, thus making it possible to fly in or above low clouds; but for landings, the cloud ceiling should be at least 500 feet and visibility 0.5 miles. These requirements would allow the pilot to land his craft under visual conditions. If these conditions are not met, it is assumed that no helicopter would be launched.

It is further assumed that one location acts as a home base for all helicopters in the system, but that helicopters can land at any of the hospitals in the system.

The emergency medical facilities in a metropolitan area may be confined to one or two hospitals or they may be spread throughout the area. Some facilities can handle all types of emergencies, while others may specialize. Some facilities are operated 24 hours a day, seven days a week, while others may only operate part of the day. The definition of a hospital for this research is a medical facility offering emergency treatment 24 hours a day for all patients. The only important restriction this places on the system is that only those emergencies requiring assistance from one of the hospitals just described plays a part in the system. If a facility offers a limited emergency service, it is not included in the system.

The calls received by hospitals and ambulance services are not all emergencies. It has been estimated that only 35 per cent of the calls are considered emergencies by the medical attendants (9). A dispatcher must decide on the nature of the call and the appropriate vehicle to send based only on the information he receives over the phone or radio and his knowledge of the terrain and weather. By establishing the rule that all highway accidents will be serviced by helicopter and by designating particular sites throughout the area as the only other helicopter pickup points, the dispatcher's problem can be made somewhat easier.

The Computer Model

This section presents a general explanation of the functions performed by each of the computer model parts and how they are related to the real system. The actual GPSS II block diagram and a printout of the computer program is included in Appendix B.

The computer model can be divided into six parts as seen in Figure 3. The key to the model is the Time Keeping section. Time is an entry in determining weather, vehicle scheduling and the accident rate. The model is designed to increment counters every ten time units where one time unit represents one minute. The Counters keep track of minutes, hours, days, months and years. Provisions are made to allow the researcher the freedom of initializing the system with the

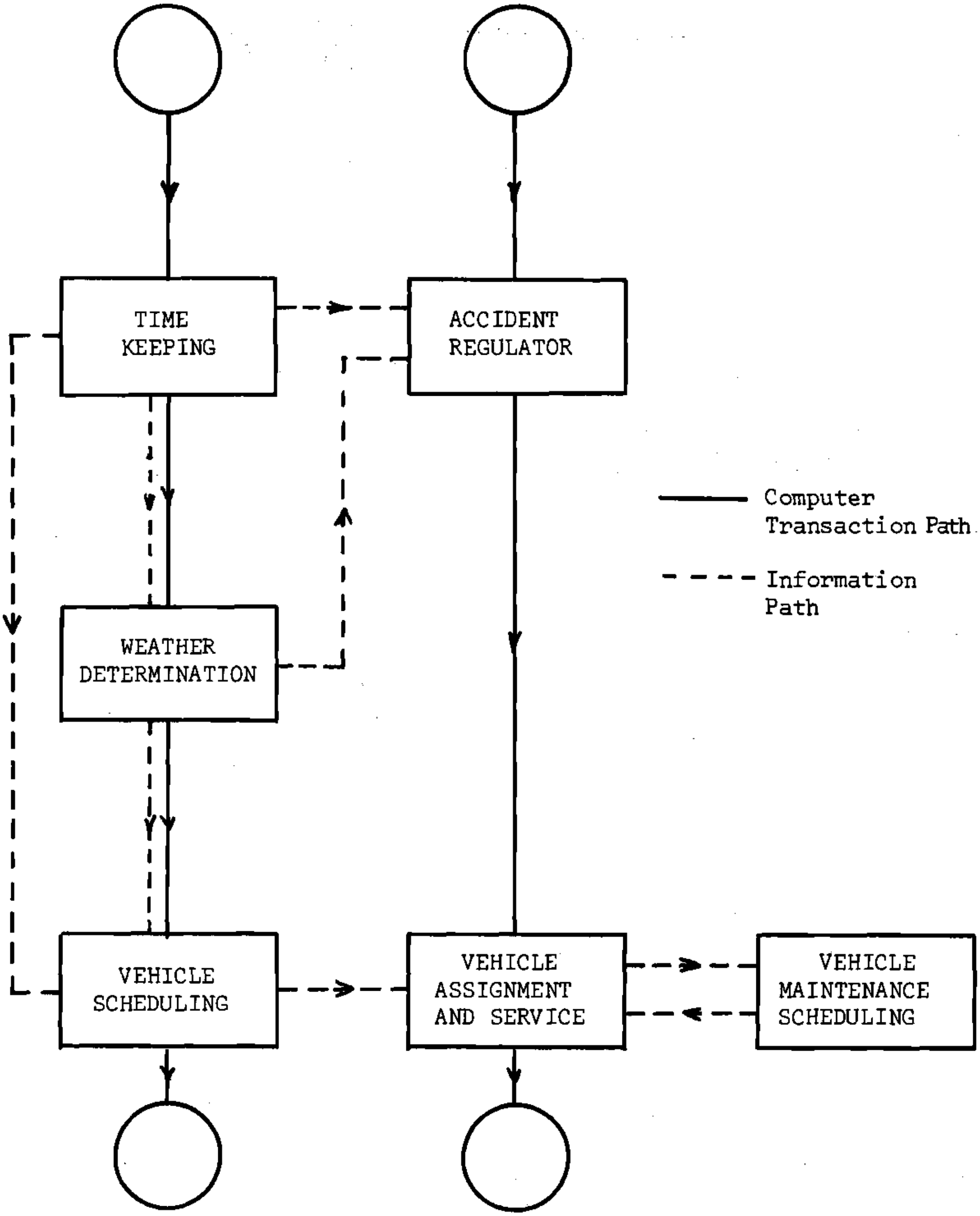


Figure 3. Block Diagram of Model Components

particular month and year he wishes to study. It is also possible to study a particular segment of consecutive years, such as the first week in April for the years 1970, 1971 and 1972.

The Weather section provides the weather condition necessary as one determinant of the type vehicle to assign a patient and the expected accident rate. The weather condition is determined from probability functions for each of the months. The data required for these functions was obtained from the metropolitan area weather summaries (10) published by the United States Weather Bureau. The duration of each type of weather was assumed to be exponentially distributed with the mean time for each type being taken from the weather data. The weather condition prevails for the prescribed duration and is then redefined. By using 12 functions to describe the 12 months, a realistic distribution of weather types was developed.

The Vehicle Scheduling section determines the number and type of vehicles available to the system. This is accomplished by "holding" all excess vehicles, thus preventing their use in servicing calls.

Groups of vehicles are assigned to particular locations in the area being simulated. A "group" of vehicles consists of seven ambulances or five helicopters. If the researcher desires to assign a location, ten ambulances and two helicopters, two groups of ambulances and one group of helicopters would be assigned to that location. The four extra ambulances and the three extra helicopters are then removed from service for the simulation, giving the system the use of the desired vehicles. This somewhat awkward procedure was necessitated by the length of statements accepted by the computer using the GPSS II language.

The next task of this section is to make vehicles available in the same quantity as the crews who man them (Figure 2). By putting the appropriate scheduling entries into a function, the number of vehicles in excess of the number of crews scheduled were removed from service until the time of day when the function indicated they should be placed in service.

The third task performed by the Vehicle Scheduling section is to remove all helicopters from service in extremely bad weather. It would also be possible to remove all ambulances with minor changes to the program, but as previously stated, it was decided not to include this rare condition.

The Accident Generation section is dependent on the Time Keeping and Weather sections, as well as a forecast of accidents for the simulated area. Although there are several forecasting techniques available, the one chosen is described in Appendix C, and it utilizes the three-factor exponential smoothing and forecasting technique. This method takes into account seasonal changes and trends, and can be easily updated when new data become available.

The forecast is for all the accidents in the month under study. The figure is divided by 30 to find the daily rate which is then multiplied by a factor to account for the time of day and the weather condition to determine an adjusted daily rate. By dividing this figure into 1440, the number of minutes in a day, the mean time between accidents is established. The accident rate is updated every ten minutes to correct it for the time of day and the existing weather condition.

The distribution of Time Between Accidents taken from hospital records closely approximated a negative exponential distribution as seen in Figure 4. The negative exponential distribution was therefore used in the model to determine accident times.

For each accident, the following characteristics are determined:

1. Hospital to receive patient.
2. Recommended mode of transportation.
3. Number of vehicles required.
4. Distance that vehicle must travel.

The hospital selection is based on the cumulative distribution of calls for all the hospitals in the system.

The mode of transportation is randomly selected based on a probability distribution for the following three modes of transportation:

I. Helicopter/Ambulance

II. Ambulance/Helicopter

III. Ambulance only.

In the first two modes, a secondary means of transportation is listed, thus providing a backup if the first type vehicle is not available. The third mode provides transportation for all patients where time is not critical or helicopter usage is not feasible.

For the most part, the number of vehicles required would be one for any single accident, but in an area where multi-patient accidents

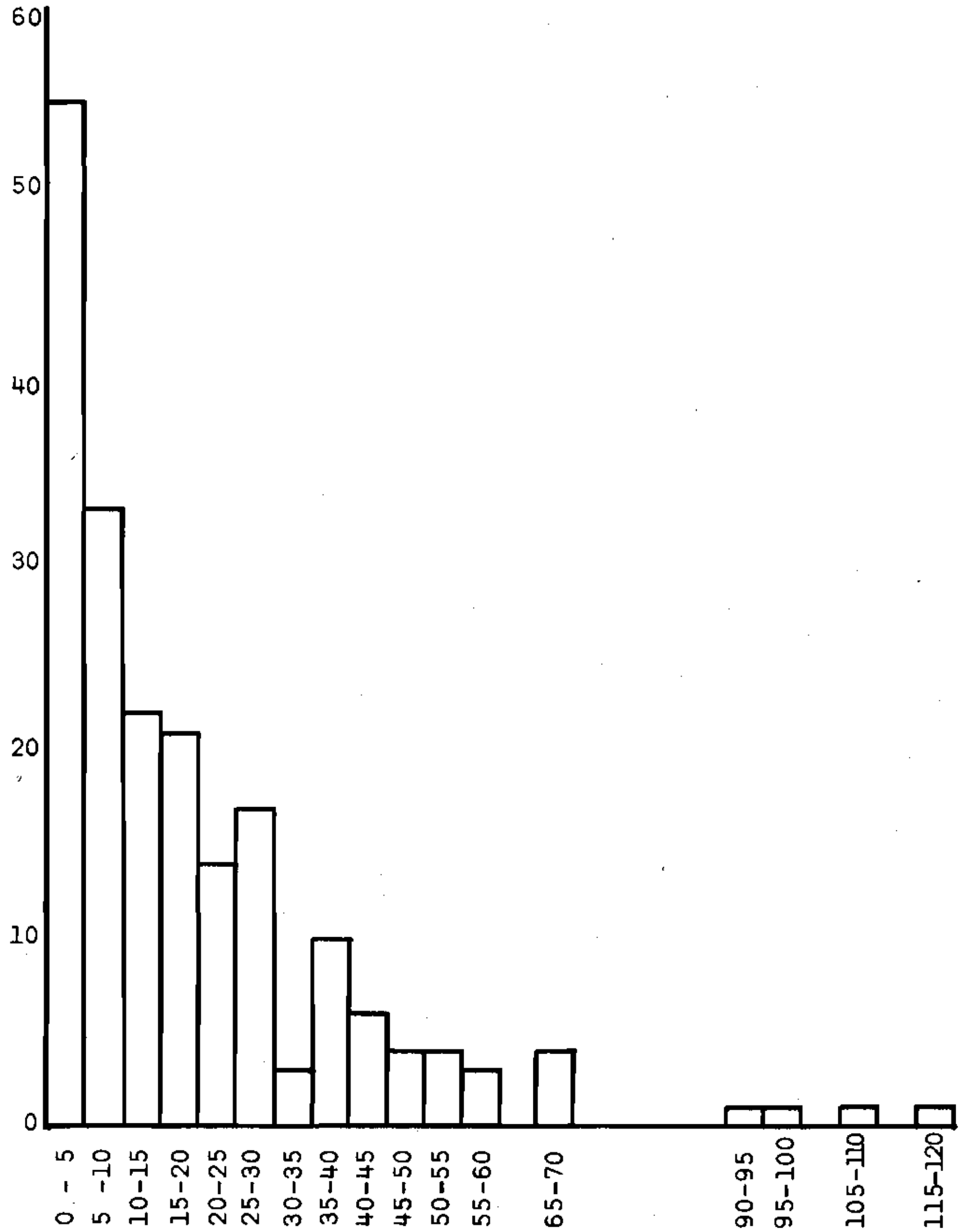


Figure 4. Time Between Accidents

are common, the researcher can establish the probability for more than one vehicle being required.

The distance between the hospital and the patient can be established from ambulance records by plotting the accident locations. For this research the distances were assumed to conform to a negative exponential distribution with a mean distance of three miles. This was not an arbitrary choice. The distribution of accidents for the Boston metropolitan area (20) was first tried, but it did not give an acceptable distribution of service times. A normal distribution was also tried with the same results. The negative exponential distribution was then tried and found to be satisfactory.

In the Vehicle Assignment and Service section the procedure for assigning vehicles is based on ranking the vehicle base location points for each hospital. If the recommended mode is one, the helicopters are checked to see if one is available. If they are all being utilized, the first through the last ambulance locations are checked to find an available vehicle. For mode three the same procedure is followed except for the check on the helicopters. Mode two requires that the primary ambulance location be checked first; then the helicopters; and finally, sequential checking of all other ambulance locations.

Service times are computed on the basis of the minimum time for the vehicle to cover the total distance to the accident and then to the hospital plus delays. The travel delay was computed by multiplying the minimum time by a factor to compensate for time of day and weather. The patient readiness delay was based on the Boston data in Appendix A.

This yields a realization of the time an ambulance is required to wait upon reaching the site of the patient.

The Maintenance section is considered pertinent only to the helicopters. It is assumed that all maintenance can be performed on the ambulances while they are not on call. It is also assumed that all minor helicopter repairs can be made during the slack periods of emergency calls, thus leaving only major overhauls to contend with. These are handled by keeping track of the hours logged by each helicopter and at the appropriate time (after a patient has arrived at a hospital) the helicopter is removed from service for maintenance. The maintenance time is somewhat arbitrary since it would depend on the type helicopter and the availability of mechanics and parts. The time used in the model was made up of two parts: a constant minimum time of three days and a variable delay exponentially distributed with a mean time of three days. Using this procedure, the mean maintenance time for overhaul was six days.

CHAPTER IV

MODEL VALIDATION AND EXPERIMENTS

The validation of the model was based on the ability of the computer program to generate data similar to actual computer data for the following distributions:

1. Ambulance Service Times.

2. Time Between Accidents.

The area being simulated for the model validation was that part of Atlanta, Georgia, serviced by ambulances from Grady Memorial Hospital. Basically this is the entire metropolitan area consisting of five counties. Backup service is provided by private companies to handle any calls above the capability of the hospital's ambulance service. The values used in the model for the validation are given in Appendix B in the computer model printout.

The distribution of service times from the hospital records was first evaluated to determine how well it could be approximated by a gamma distribution (Figure 5). The theoretical gamma distribution data given in Table 1 were obtained from Pearson's "Tables of the Incomplete Gamma Functions" (16). The distribution of the computer data is also given in Table 1, thus giving the comparison of the data from the three sources.

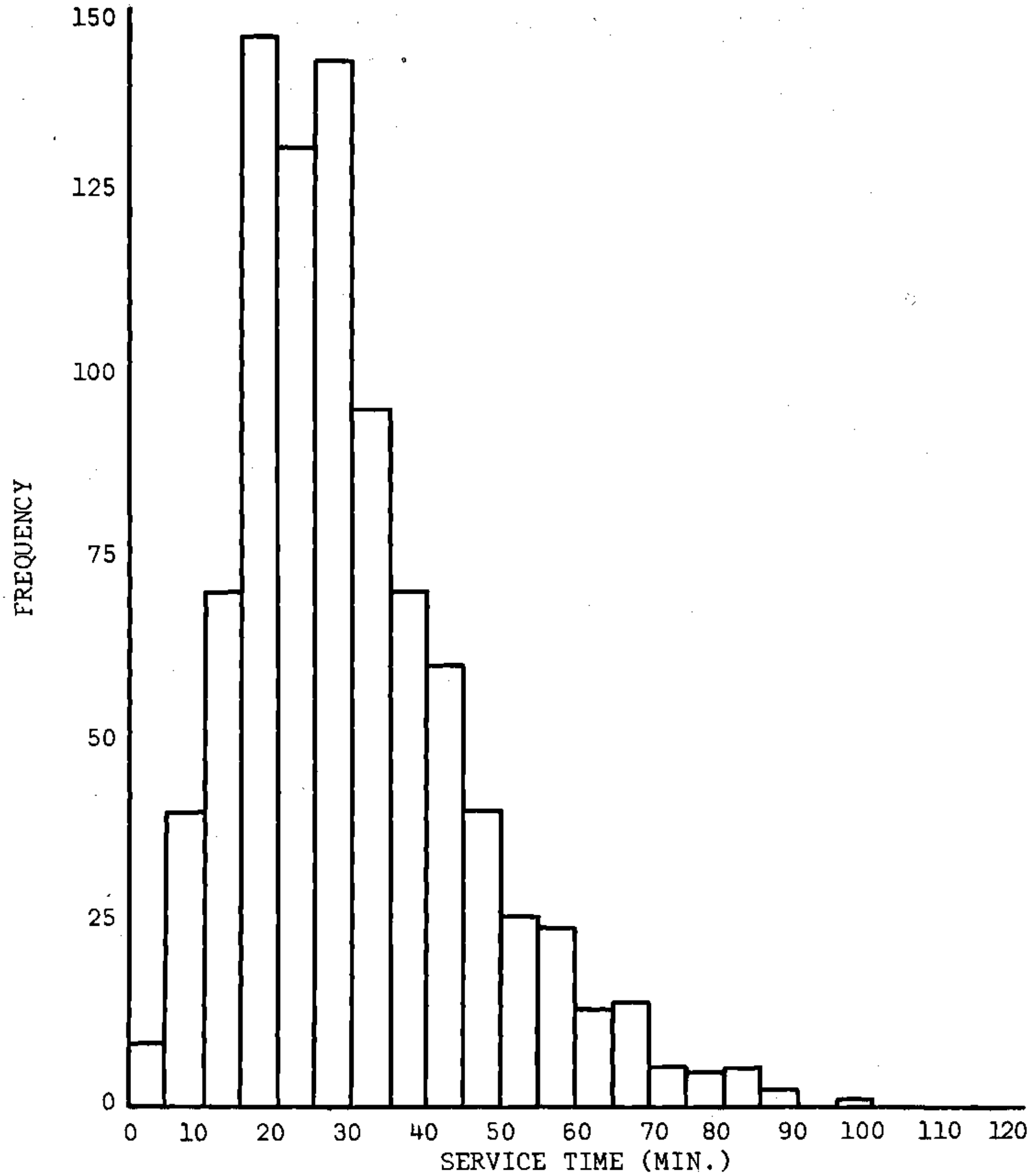


Figure 5. Distribution of Service Times

Table 1. Distribution of Service Times

Time Period: Five-Minute Intervals	Hospital Data f_D*	Hospital Data F_D**	Theoretical Data f_D*	Theoretical Data F_D**	Computer Data f_D*	Computer Data F_D**	Difference Values Between Cumulative Distributions $D_{D,T}$	Difference Values Between Cumulative Distributions $D_{D,C}$
1	8	.009	4	.004	0	.000	.005	.009
2	41	.055	38	.047	47	.051	.008	.004
3	70	.133	97	.155	134	.195	.022	.062
4	147	.296	137	.308	150	.356	.012	.060
5	132	.443	148	.473	134	.500	.030	.057
6	143	.603	134	.621	119	.628	.018	.025
7	95	.708	108	.743	105	.741	.035	.033
8	70	.786	78	.830	52	.797	.044	.011
9	60	.853	56	.892	43	.844	.039	.009
10	40	.898	40	.934	10	.854	.036	.044
11	26	.927	25	.960	32	.890	.033	.037
12	24	.953	20	.976	7	.897	.023	.056
13	13	.968	10	.986	16	.915	.018	.053
14	14	.983	7	.992	14	.930	.009	.053
15	5	.989	3	.996	13	.944	.007	.045
16	4	.994	2	.997	4	.948	.003	.046
17	4	.998	1	.998	3	.951	.000	.047
18	2	.999	1	.999	11	.963	.000	.036
19	1	.999	1	.999	2	.965	.000	.034
20	1	1.000	1	1.000	2	.967	.000	.033

*Frequency of calls.

**Cumulative distribution of calls.

It is unlikely that two distributions developed by different means would have all points identical. It is necessary, however, for the distribution from the simulation experiment to conform closely to the observed service time distribution. The Kolmogorov-Smirnov goodness-of-fit test was used to test the hypothesis of distribution conformity. The test is based on comparing the maximum difference between two cumulative distribution to the acceptable deviation limit

$$L \sqrt{\frac{N_1 + N_2}{N_1 N_2}}$$

where L is the significance level factor (3) and N_1 and N_2 are the numbers of elements in the two samples on which the distributions are based. For a significance level of 0.05, L = 1.36. If the maximum difference is greater than the limit, the hypothesis of distribution conformity is rejected. To determine how well the distribution of service times fits the gamma distribution the following acceptable deviation was determined.

$$1.36 \sqrt{\frac{900 + 900}{(900)(900)}} = .0642$$

Since the maximum difference between the cumulative distributions based on the hospital data and the theoretical distribution is less than .0642, the hypothesis of distribution conformity is not rejected. The same test was performed with the distribution from the computer model and the actual hospital data distribution. Since the maximum difference between the curves was .0620, the hypothesis of distribution conformity was again not rejected.

Although the Kolmogorov-Smirnov test was designed to be used with ranked serial data, little error is introduced if it is employed with grouped data so long as the sample sizes are large (3,11,18). The Chi-Square goodness-of-fit test was tried, but irregularities in the hospital data made this test too critical for the service time distribution.

The distribution of time between calls (Figure 4, Chapter III) was first tested for conformity to a negative exponential distribution. Using the equation

$$F_{(t)} = 1 - e^{-\lambda t}$$

where $\lambda = 1/\bar{X}$ and $\bar{X} = 19.86$ minutes, the theoretical cumulative distribution was calculated (Table 2). The acceptable deviation for a significance level of 0.05 is

$$1.36 \sqrt{\frac{676 + 676}{(676)(676)}} = .0740$$

Since the maximum difference between the cumulative distribution of the hospital data and the theoretical distribution is only .034, the hypothesis of distribution conformity was not rejected. The computer data was also within the accepted limits with a maximum difference of .057.

Table 2. Distribution of Time Between Calls

Time Period: Five-Minute Intervals	Hospital Data		Theoretical Data		Computer Data		Difference Values Between Cumulative Distributions	
	f_D*	F_D**	f_T*	F_T**	f_C*	F_C**	$D_{D,T}$	$D_{D,C}$
1	172	.254	138	.200	160	.230	.024	.024
2	95	.394	109	.360	103	.378	.034	.016
3	76	.506	88	.488	75	.485	.018	.021
4	75	.617	71	.591	78	.599	.026	.018
5	53	.695	55	.672	53	.674	.023	.021
6	49	.767	45	.738	43	.736	.029	.031
7	33	.816	38	.791	38	.797	.025	.019
8	34	.866	28	.833	20	.826	.033	.040
9	20	.895	23	.866	17	.852	.029	.043
10	20	.925	19	.893	11	.868	.032	.057
11	10	.940	12	.914	14	.889	.026	.051
12	11	.956	10	.932	8	.900	.024	.256
13	8	.968	8	.945	10	.914	.023	.054
14	5	.975	7	.956	8	.931	.019	.044
15	2	.978	6	.965	10	.947	.013	.031
16	4	.984	4	.972	6	.955	.012	.029
17	4	.990	4	.977	11	.963	.013	.027
18	6	.999	4	.982	4	.968	.017	.031
19	1	1.000	3	.986	3	.973	.014	.027

*Frequency of calls.

**Cumulative distribution of calls.

Experiments

Forecasting

The model contains a forecasting procedure for updating the accident rate for the particular month and year being studied. To demonstrate this procedure, the model was run to simulate a five-day period in January, April, July, and October, 1970. The model was run to simulate five days in January, 1971 and January, 1972. The monthly forecasts are always obtained and printed out. The resulting monthly rates are shown in Figure 6. Only the Ambulances were simulated in this experiment since the primary objective was to validate the forecasting procedure.

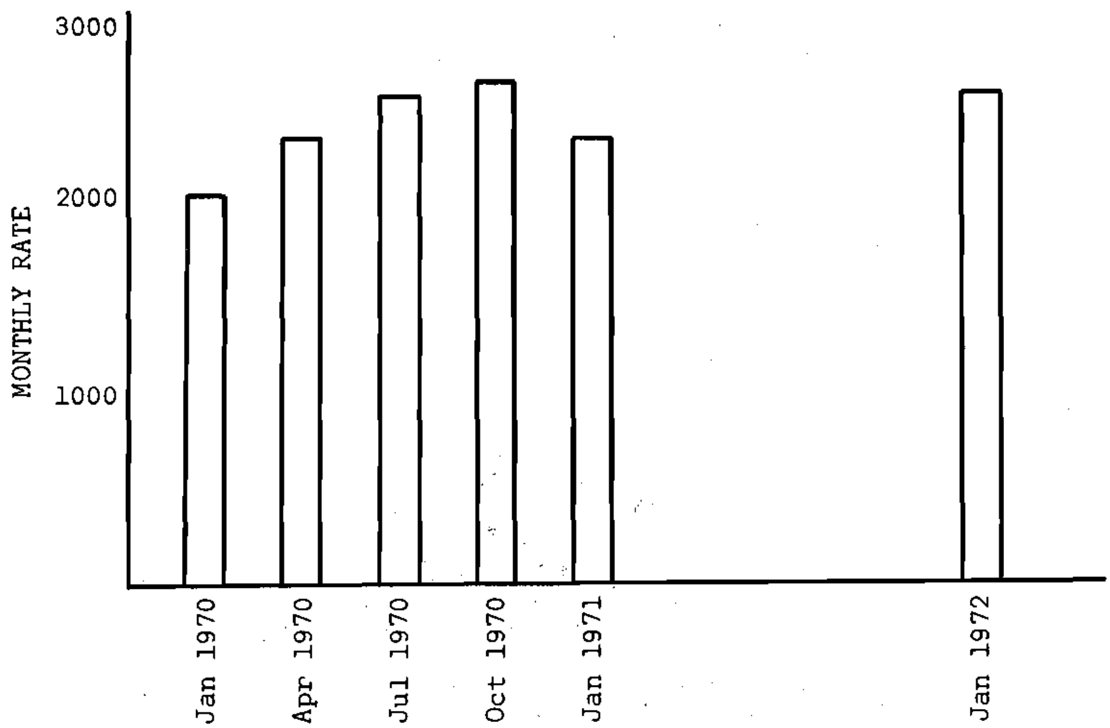


Figure 6. Computer-Forecasted Accidents

The results of the computer run were easily substantiated using the formula

$$F_{t+T} = (\bar{X}_t + T\bar{G}_t)\ \bar{S}_{(t+T-L)}$$

which is the basis of the model's procedure as discussed in Appendix B where $\bar{X}$ is the average rate taken from existing data; T is the number of the period being forecast; $\bar{G}$ is the average trend; and $\bar{S}$ is the seasonal effect. For January, 1970, T = 25, $\bar{X}_{24}$ = 1683, $\bar{G}_{24}$ = 25 and $\bar{S}_{(24+25-24)}$ = .890. This yields $F_{49} = (1683+25^2)(.890) = 2054$ which agrees with the computer output.

Seasonal Fluctuations

Service times fluctuate as a result of weather conditions. The effect of weather can be shown by comparing the mean service times for different times of the year. Since no queues are allowed to build up in the system, the seasonal effect on the accident rate does not affect the service times. The change in service time is therefore a reflection of the weather effect. The months of January, April, July and October of 1970 were simulated and the resulting mean service times are shown in Figure 7. The lack of radical changes in service times agree with the relatively mild weather in the Atlanta area. The advantage of adding a helicopter to the system is nearly uniform for all seasons in the Atlanta area; however, a slight variation was shown over the four test periods. The five-day period for each season is too short for a conclusive statement on the seasonal effects.

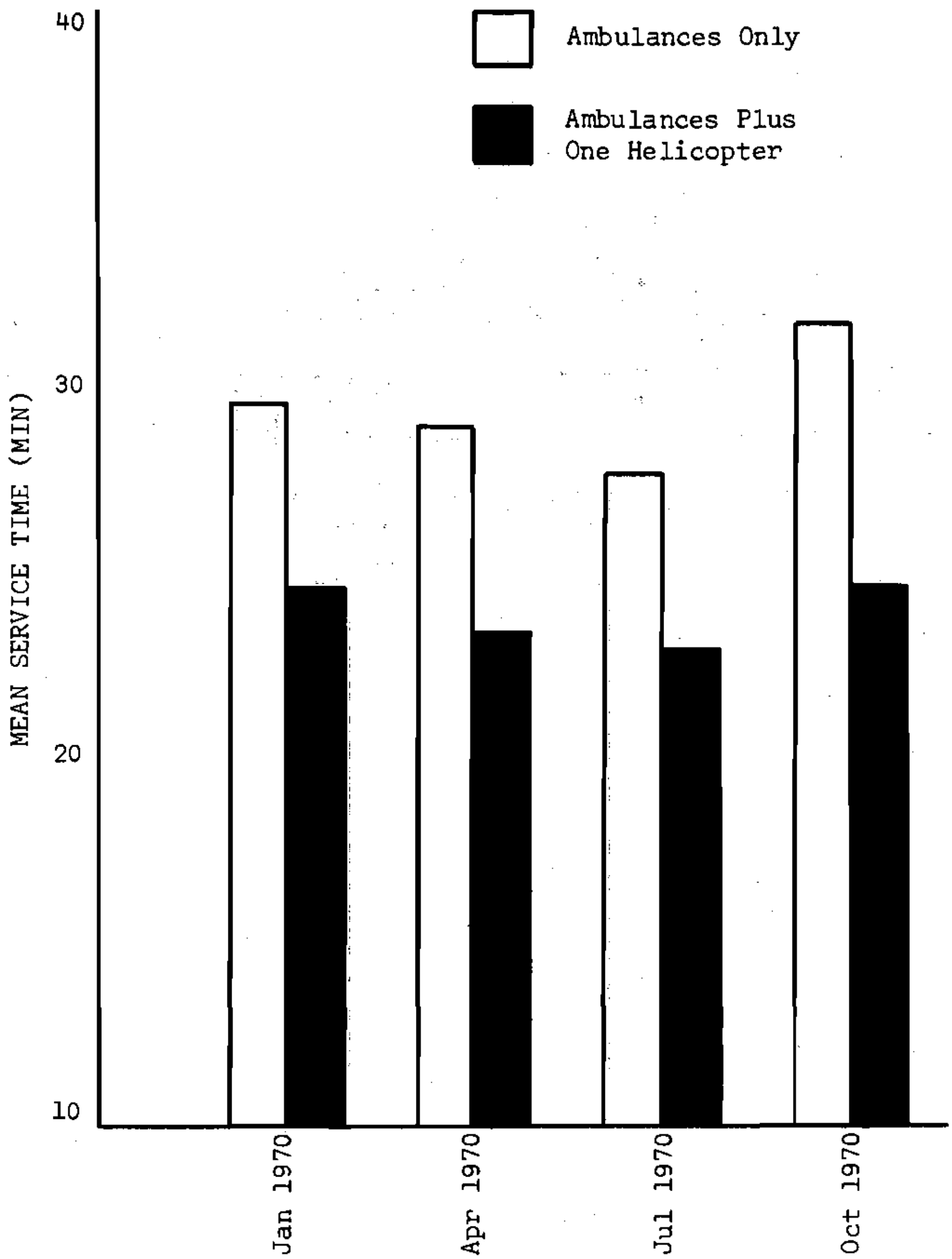


Figure 7. Seasonal Effect on Service Times

System Including Two Helicopters

To determine the effect of having more than one helicopter in the system, a second helicopter was added. The number of requests for helicopters was not changed. The distribution among modes was 30 per cent mode I, 40 per cent mode II and 30 per cent mode III. The effect on mean service time was a decrease from 24.74 minutes to 23.02 minutes. The percentage of calls answered by helicopter rose from 29.0 to 33.2. With only one helicopter in the system, the helicopter was utilized 15.11 per cent of the time. The addition of the second helicopter resulted in one helicopter being utilized 15.03 per cent while the second craft was utilized only 3.02 per cent. Since the advantages gained by adding a second helicopter appeared to be small, no computer runs were made with additional helicopters.

Helicopter Utilization

Three levels of mode I calls were tested to determine the effect on the helicopter utilization. The levels were 10, 30 and 50 per cent. The level of mode II calls remained constant at 40 per cent for the three runs. The effect on the system can be seen in Table 3.

Table 3. Helicopter Utilization

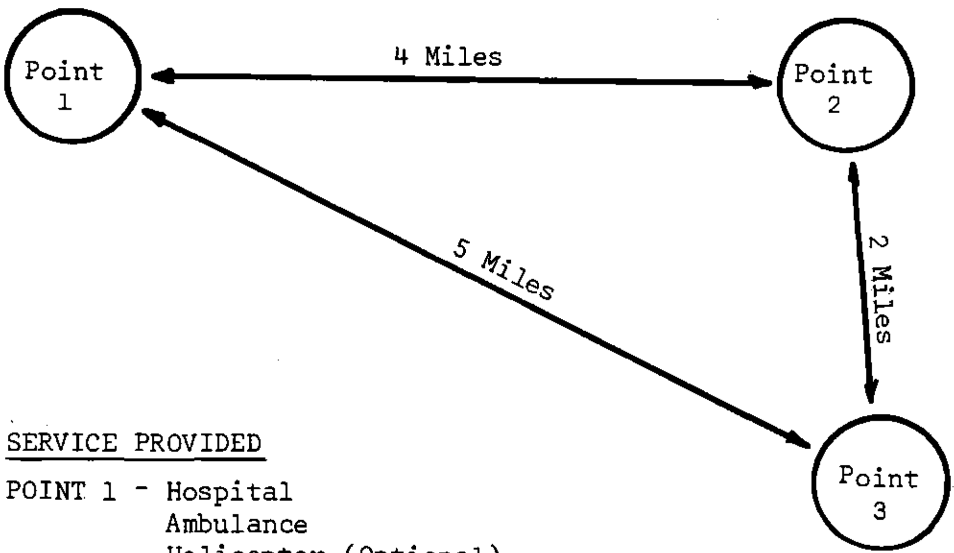
	RUN		
	1	2	3
Mode I Calls (%)	10.00	30.00	50.00
Mode II Calls (%)	40.00	40.00	40.00
Mode III Calls (%)	50.00	30.00	10.00
Helicopter Utilization (%)	9.06	20.18	27.88
Calls Answered by Helicopter (%)	12.00	27.30	37.80
Mean Service Time (Minutes)	24.74	23.59	18.90

By allowing a greater number of calls to be serviced by helicopter, a definite advantage was realized on the mean service time. The single helicopter could not provide service for all mode I calls although its utilization was reasonably low (27.88 per cent for the highest level of mode I calls). The main factor contributing to this was the uneven distribution of accidents throughout the day. The time between calls during the heavy traffic hours was too short to allow one helicopter to service one call before the next call was received; therefore ambulances were dispatched when needed to provide immediate response to all calls.

Enlarging the System

The computer model was designed to function with one or more hospitals and one or more vehicle groups. To determine the effect of enlarging the system, a second hospital was added at a point four miles away from the first hospital and an additional ambulance group was added at a third point as seen in Figure 9. Ambulances from either point one or point three were allowed to service calls for either hospital; however, the ambulance group assigned to the hospital at point one acted as the primary service for that point and the ambulance group at point three acted as the primary service for the hospital at point two. The accident rate for this experiment was increased 50 per cent over previous runs. The hospital at point two was then designated to randomly receive 33 per cent of all calls.

The effect on the over-all mean service time for the system was virtually unchanged at 30.34 minutes; however, when a helicopter was added to the system operating from point one but answering calls for both hospitals, the mean service time was 26.50 compared to 24.74 for the one hospital system. With the stipulation that service must be provided to the designated hospital and not to the closest hospital, the helicopter had a minimum distance of four miles to travel for all calls to the second hospital. Since the average distance for service provided by the helicopter increased, the over-all mean service time also increased.



<u>SERVICE PROVIDED</u>

POINT 1 - Hospital
Ambulance
Helicopter (Optional)

POINT 2 - Hospital Only

POINT 3 - Ambulance Only

Figure 8. Layout of Service Points for Expanded System

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The Computer Simulation

The results of the computer simulation for the Grady Memorial Hospital ambulance service satisfied the requirements of the Kolmogorov-Smirnov test for the distributions of time between accidents and service times. The large samples of data values used for each test added assurance to the results since limits of acceptance for this test decrease as the number of samples increases.

The effect of adding a helicopter to the model made an appreciable change in the distribution of service times. As shown in Figure 7, Chapter IV, the addition of a helicopter reduced the mean service time about five minutes with some variation between seasons. The model did not assign all long distance calls to helicopters, therefore, although the distribution mean is shifted substantially downward, a few calls still require long service times. This conforms to the expected results of a real system since some long distance trips could not, or should not receive the faster, more expensive helicopter service. The real advantage was to the patients requiring fast service. The mean service time for helicopter service was 12.33 minutes compared to 29.47 minutes for ambulance service.

A second helicopter added to the system made little change in the mean service time of the system. The additional helicopter primarily served to answer calls received while the first helicopter was busy. The percentage of patients serviced by helicopter increased from 29.0 to 33.2. Unless some other use could be made of the helicopters during periods of few accidents, the requirement for more than one helicopter would seem very difficult to justify in the system studied.

Table 3 of Chapter IV indicates the expected results of assigning a helicopter different percentages of emergency calls. With an assignment of 30 or 50 per cent of all calls, part of the calls had to be serviced by ambulance since the helicopter was not available when the calls were received. At the 30 per cent level, 27.3 per cent of the calls were actually serviced by helicopter, and at the 50 per cent level, only 37.8 per cent of all calls were answered by helicopter.

Recommendations

The following recommendations are offered for future research:

1. The model should take into account the total distance to be traveled in deciding if a helicopter should be used to service a call. By servicing a greater majority of long calls by helicopter, the mean service time should be reduced and better utilization of vehicles should be realized.

2. The model should be expanded to include medical facilities other than those operating 24 hours a day.

3. A comparison should be made between the use of the helicopter/ambulance system and critically placed ambulances. By having ambulances at high accident points, considerable time may be saved by

the ambulances, thus possibly making this type system competitive to the mixed system with regard to service times.

4. An evaluation should be made of the benefits of using strategically placed ambulances to deliver patients to points where helicopters can speed the patients to centrally-located hospitals.

5. An extensive test program should be run using data on all ambulance systems in a city for various accident rates up to the point of saturating all emergency transportation means. Types of vehicles should be varied at the saturation level to determine maximum differences in systems of vehicles.

6. An economic study should be performed to compare the various combinations of vehicles. Factors to be considered should include the cost associated with:

a. Initial procurement.

b. Maintenance.

c. Replacement.

d. Insurance.

e. Communication.

f. Crews.

g. Training.

h. Heliports.

APPENDIX A

AMBULANCE SERVICE DATA

Table 4. Ambulance Service Data

Distance one way, duration, and time of departure of ambulance trips, Boston City Hospital (9).

Characteristics of Trips	Number of Trips	Per Cent of Trips
Total	432	100
Distance (Miles):		
Less than 1	44	10
1-3	152	35
4-6	132	31
7-10	68	16
More than 10	4	1
Not specified	32	7
Duration:		
10 minutes	8	2
10 to 20 minutes	50	11
20 to 30 minutes	112	26
30 to 45 minutes	95	22
45 minutes to 1 hour	84	19
1 to 1-1/2 hours	51	12
1-1/2 to 2 hours	8	2
More than 2 hours	8	2
Not specified	16	4
Time of Departure:		
8 a.m. to noon	136	32
Noon to 4 p.m.	128	30
4 p.m. to 8 p.m.	56	12
8 p.m. to midnight	48	11
Midnight to 4 a.m.	12	3
4 a.m. to 8 a.m.	20	5
Not specified	32	7

APPENDIX B

THE COMPUTER MODEL

APPENDIX B

THE COMPUTER MODEL

The computer model can be divided into sections which perform particular functions. Each section will be explained along with its effect on all other sections.

Time Keeping

Figure 9 is a block diagram of the time keeping section. This section keeps track of the minutes, hours, days, months and year being studied. A set of SAVEX locations stores the information for later use in determining weather conditions and accident rates.

The left and center columns of blocks of Figure 9 function in response to transactions from the ORIGINATE block (number 100). A transaction enters block 101 every 10 minutes (or time units) and causes 10 units to be added to X100, the minute counter. The transaction then tries to enter block 102, which is a COMPARE block, and if the value stored in X100 is less than 60, the transaction is allowed to enter and go directly to block 114. If the value in X100 is 60, it is time to increment the hour counter and the transaction is sent to block 103 which sets X100 back to zero. The transaction then passes on to block 104 and increases the hour counter (X101) by one. The same procedure is followed for the hour, (X101), day (X102) and month (X103) counters as with the minute counter. When the proper amount of

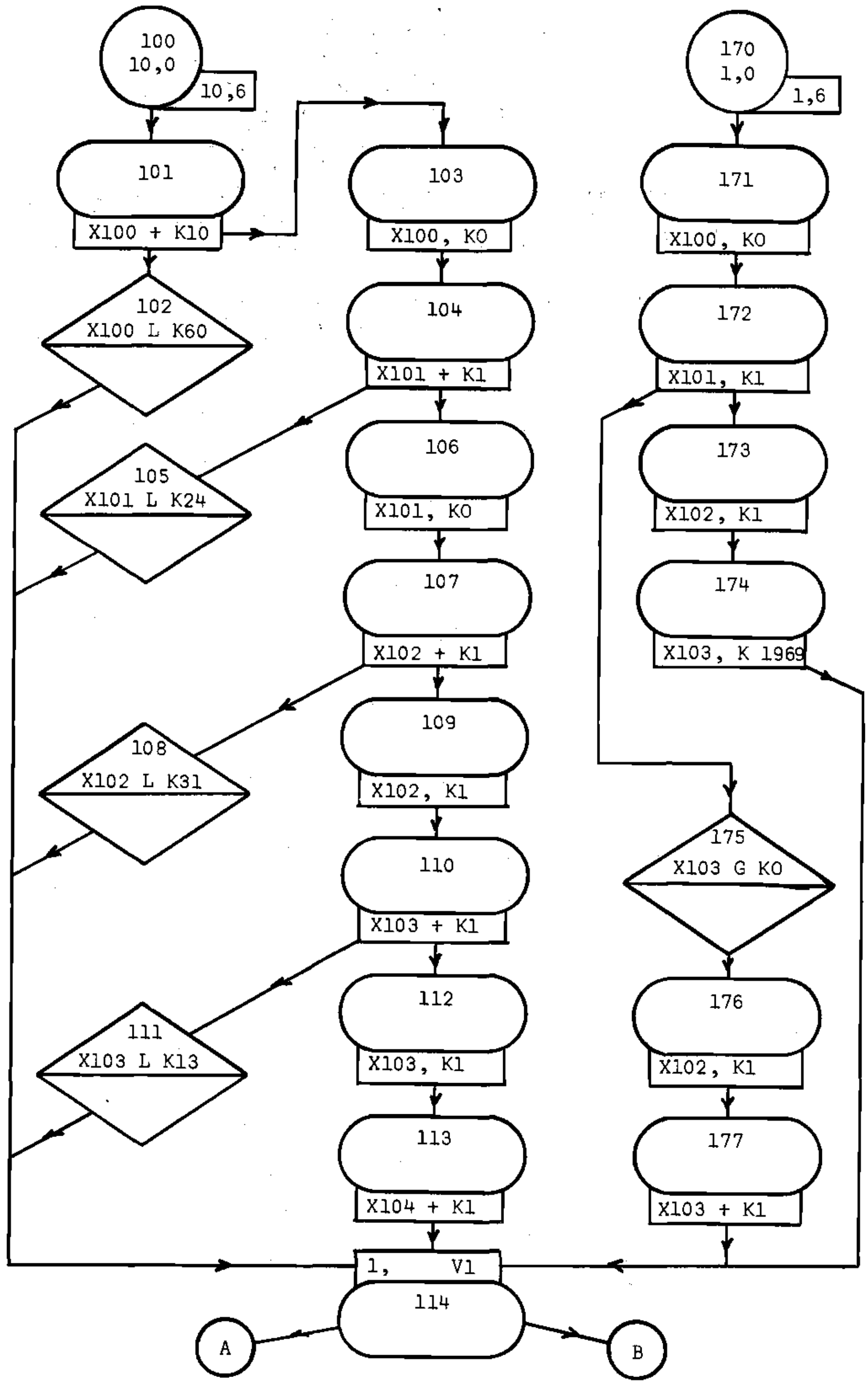


Figure 9. Time Keeping Section

time has been stored in a counter, it reverts back to its starting point and the next higher counter is incremented by one.

Block 114 is an ASSIGN block which assigns to parameter one a value equal to the month (1 for January to 12 for December) plus 50. This parameter value is used later to call out FUNCTIONS 51 through 62 which describe the weather distribution for the different months. This will be covered in the next section.

The right-hand column of blocks in Figure 9 are the initialization blocks for the time keeping section and can be manipulated by the researcher to indicate the period he wishes to study. The month (block 173) and year (block 174) are probably the only blocks the researcher would want to change. Block 173 shows X102 set at one but any value from one to 12 could be set in to indicate the month to be studied. The same procedure can be followed with block 174. Any year beyond 1967 can be set into X103.

If a continuous period is to be studied, the ORIGINATE block, 170, contains the necessary information. As soon as the program starts operating a single transaction is sent through the SAVEX blocks indicated and the rest of the program can then operate correctly. No other transaction is required from block 170 and therefore the ORIGINATE becomes inactive.

If a particular month is to be studied for different years, a START card must be present for each period. Blocks 170, 173 and 174 must also be redefined for each period and CLEAR cards must be appropriately placed after all but the last START, thus setting all blocks to zero at the beginning of each run. Block 174 must now contain a constant of K1970.

<u>Weather</u>

As a transaction leaves the Time Keeping section it first tries to enter the COMPARE block, 115 (Figure 10). If the transaction is the first of the run, the value in X107 is zero and the transaction can enter block 115 and pass into block 116. Block 116 establishes the weather type based on the function whose number is given by parameter one. As previously mentioned these functions are numbered from 51 through 62. Each function is based on the probability of different types of weather in that month.

Block 117 established the duration of the weather type and stores it in X106. The duration is determined by VARIABLE 7 which takes a mean value for a particular weather type and multiplies it by the exponential function, FUNCTION 30.

Next, the transaction goes to block 118 and sets X107 equal to the current clock time plus the weather duration given in X106. This establishes the time when another transaction should be routed through blocks 116-118. Until the clock time, C1 increases to the value of X107, transactions are not sent through block 115 but on to block 122. Block 119 permits all weather to be printed along with the time it started and time it ended.

If the weather condition is such that helicopters cannot fly (X105 less than 3), the transaction leaving block 119 is permitted to pass through the COMPARE block, 120, and into the ASSIGN block, 121,

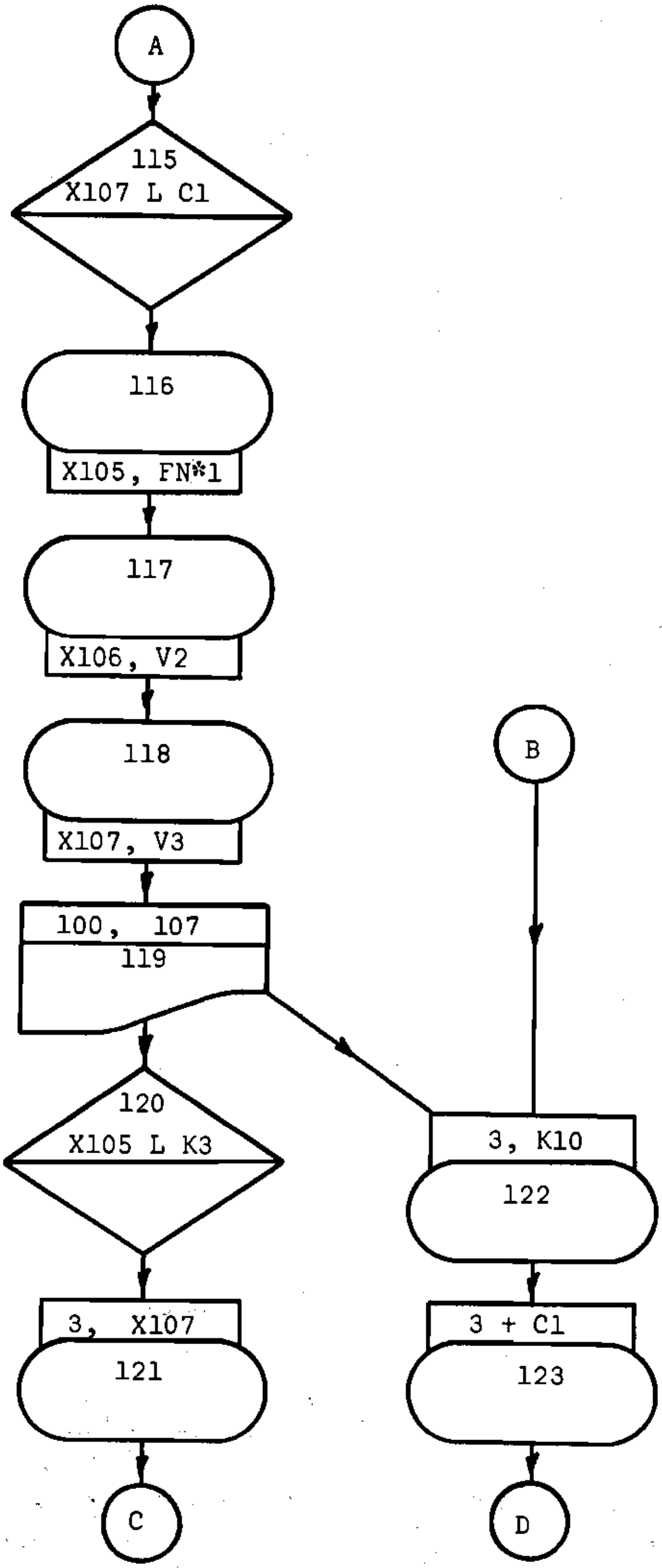


Figure 10. Weather Section

where parameter three is set equal to the time when the weather is scheduled to change as noted in X107. The transaction is then ready to pass on to the Vehicle Scheduling section of the program. If bad weather is not present, the time of the next transaction is recorded in parameter three by the use of the ASSIGN blocks 122 and 123.

Vehicle Scheduling

The Vehicle Scheduling section works on the basis of "capturing" excess vehicles in the system. Vehicles are considered excess if too many are assigned to one location, thus not conforming to the system being simulated. Excesses also exist when no crews are scheduled for a particular part of a day. A transaction entering this section by path "C" indicates bad weather where all helicopters programmed in the system are to be kept down. If a transaction enters by way of path "D", the researcher has the option to make any combination of vehicles available.

Figure 11, block 125 indicates parameter four receives a value of four indicating four helicopters are to be kept out of operation at all times, thus allowing one helicopter to be on call. Later in the discussion on ambulance scheduling it will be shown how the number of vehicles can be made changeable by time of day.

Both blocks 124 and 125 send transactions into the SPLIT block, 126. Blocks 126 and 127 work together to "Split off" as many transactions as are dictated by parameter four. Thus, from one transaction entering from the Weather Section, block 127 receives four or five transactions depending on whether the entry was made on route "D" or

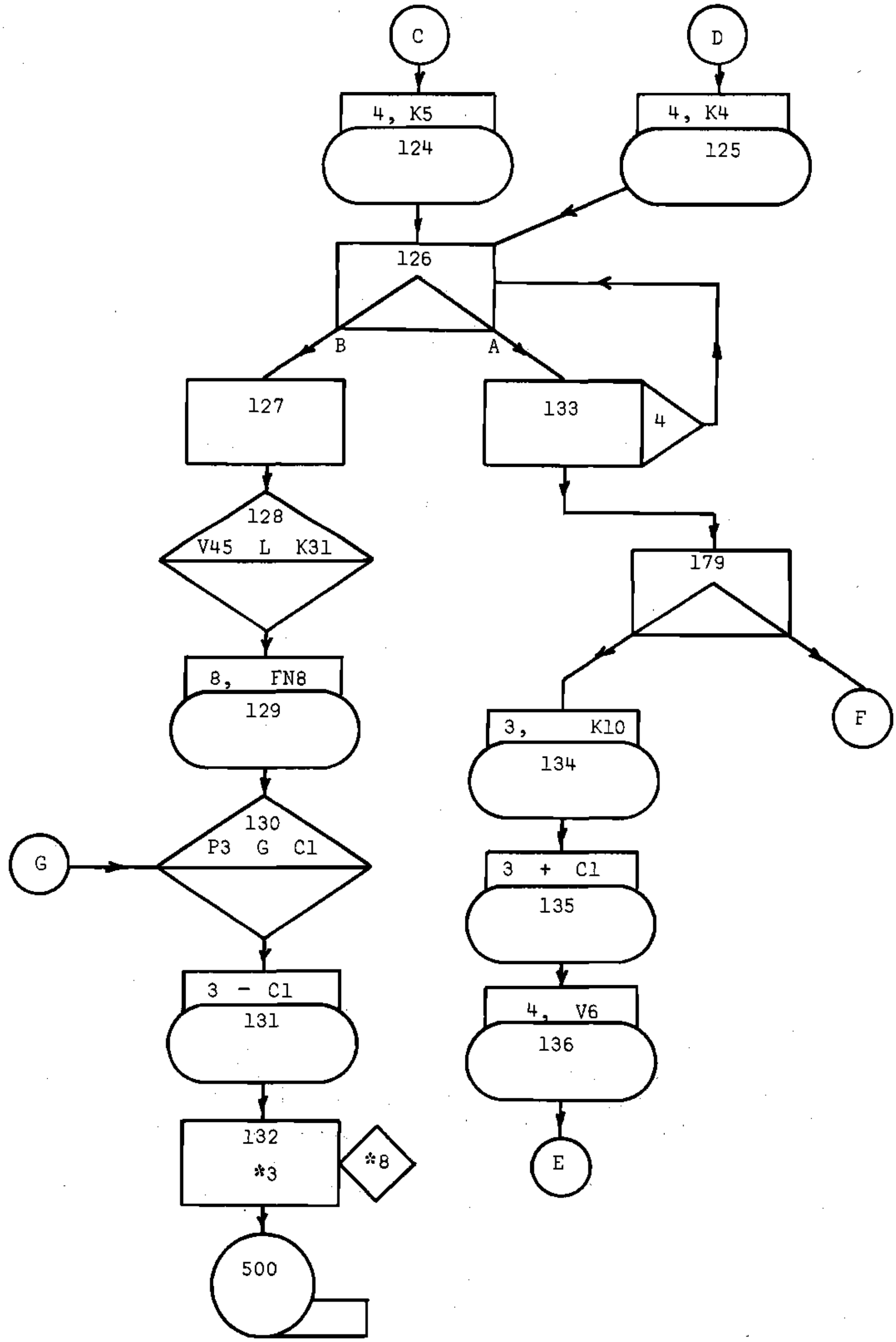


Figure 11. Helicopter Scheduling

"C", respectively. The last transaction entering the LOOP block, 133, is sent to block 179 which starts the ambulance scheduling.

The COMPARE block, 128, makes use of the GPSS II procedure of assigning a value of zero to all empty facilities and a value of one to all facilities in use. The helicopter facilities are numbered 81 through 85. By defining VARIABLE 18 as

K16*F81+K8*F82+K4*F83+K2*F84+F85

where the asterisk signifies multiplication of the facility value by the constant indicated, it is possible to determine if any facility is not in use and if so, which one it is. If all facilities are full, the value of the variable is 31. Any value less than 31 means a facility is empty and a transaction is allowed to enter block 128.

Block 129 assigns to parameter eight of each transaction the number of a vacant facility. This is accomplished by entering FUNCTION 8 (FN8) with VARIABLE 18 (V18). If the value of V18 is, say 15, this indicates that facility 81 is empty since the value of V18 has been reduced from 31 by 16. In fact, if V18 is any value less than 15, then facility 81 must be empty as well as at least one other facility. By the same procedure it can be shown that values of V18 from 16 to 23 can only occur if facility 82 is empty; and so on for each facility.

It is possible for more transactions to try to enter block 128 than there are empty facilities. If a transaction must wait, the clock time (C1) may increase until the value of parameter three is smaller than the clock time, indicating that the transaction should no longer hold a facility. When the transaction enters block 130, if parameter three is greater than C1 the difference is assigned to parameter three replacing the old value. The assigned facility is then occupied for the time indicated by parameter three. If, however, the check at block 130 shows C1 equal to or greater than parameter three, the transaction is terminated at block 500 as are the transactions which eventually leave block 132.

Block 132 is a HOLD block and it allows a transaction to occupy the facility designated by the transaction's parameter eight. This is called "indirect specification of a facility" and allows great economy of blocks since one block can be used for many facilities. The three blocks 130, 131 and 132 are also used for the ambulance scheduling, this being possible by the use of indirect specification.

The last time a transaction passes through a LOOP block, it is sent to the block specified in the "Next Block B" field on the LOOP card. Block 133 sends the transaction to block 179. This split block is used to allow for normal progression through the ambulance part of the Vehicle Scheduling section, while at the same time the conditions for the accident rate can be established. This procedure is discussed in the next section.

The transaction which entered block 134 from block 179, resets parameter three to the value of the current clock time plus ten. It should be noted that this transaction has used no clock time from the time it was originated in block 100. On its entire path it did not enter a block which required it to spend any amount of time. Therefore, if the transaction started at time 60, it would arrive at block 134 at time 60 and would continue to set up all the ambulance scheduling for the other vehicle groups in the system, and then terminate at time 60. Only in block 132 of this section does a transaction stay while the clock advances.

A transaction leaving block 135 enters the ASSIGN block 136 and parameter four is set equal to the number of ambulances which are to be taken out of service. This is accomplished by having the desired number of vehicles for each hour set in Function 50. Variable six subtracts the value found in Function 50 from the number of ambulances in a group (seven) to give the number to be removed from service. As an example, if at 4:00 P.M., Function 50 yields a value of five, the number of vehicles to be taken out of service is two. The input to FUNCTION 50 is the current hour of the day of the simulation. Blocks 137 and 138 (Figure 12) "split off" the correct number of new transactions required by parameter four in the same manner as was earlier discussed about blocks 126 and 133 for the helicopter scheduling. The transactions are held in block 138 awaiting a free facility to be indicated by block 139. The Facility number is then assigned to the transaction's parameter eight and the transaction moves on to block 129 to continue the process as previously discussed.

A different set of Facilities is used for the ambulances than were used for the helicopters. The seven ambulances used as the total number in V46 represent one group or those assigned to one geographical

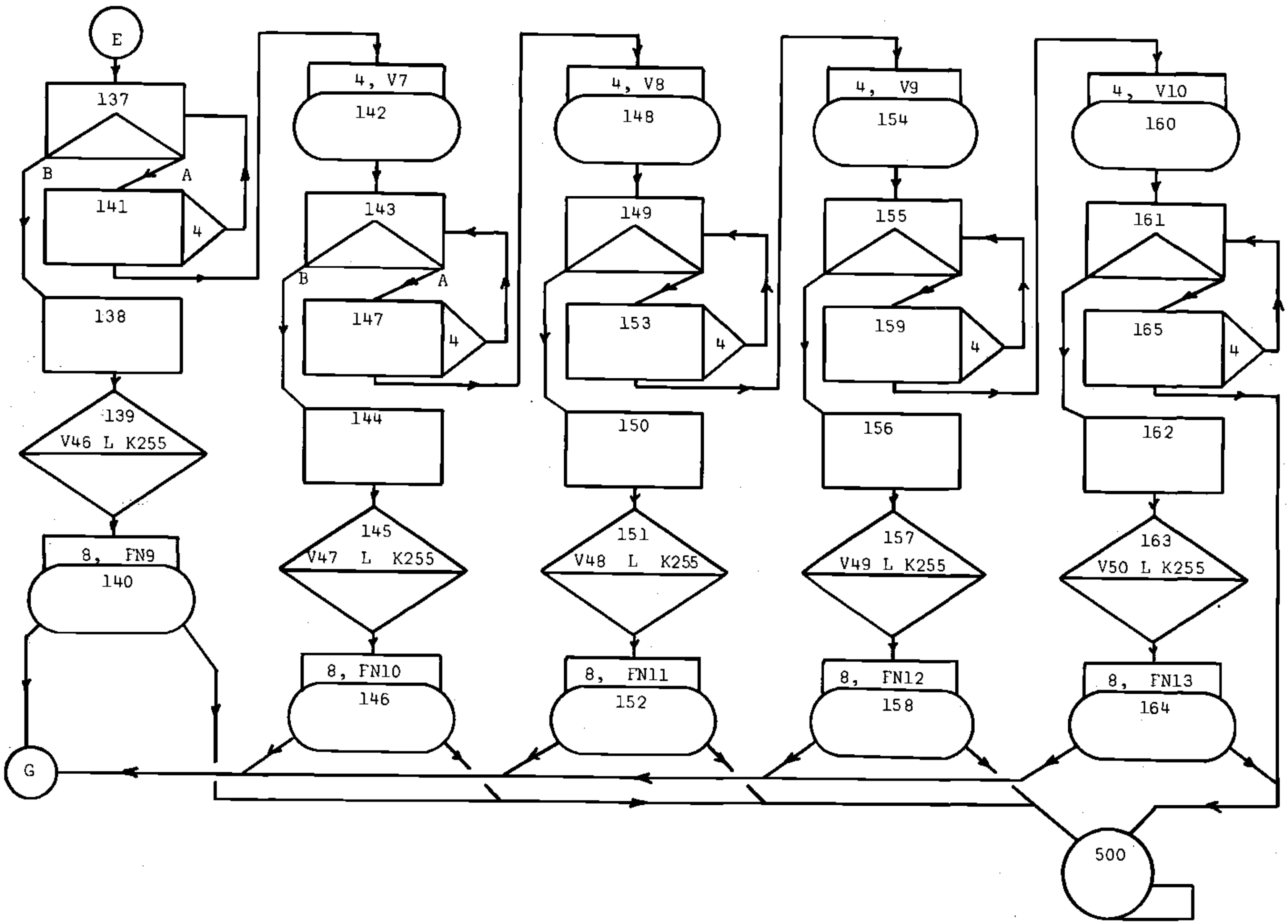


Figure 12. Ambulance Scheduling

location. Seven facilities are the maximum that can be represented on one VARIABLE card. A larger number of vehicles can be assigned to one location by use of more than one group.

Accident Generation

The number of accidents that will occur in any given period and consequently the average time between accidents must be established before accident generation can commence. A transaction was split in block 179 and one of the new transactions was sent to block 180 to establish the necessary accident information. The information is updated every ten minutes of the simulation. Many of the following steps had to be taken separately and the information stored in SAVEX locations because of the interplay between functions, variables and previously stored information.

Blocks 180 through 186 are SAVEX blocks used to store complex bits of information (see Figure 13). The first step is to determine the particular number of years in the future from the program year that is being simulated. V19 says to subtract 1968 from the year found in X104. If X104 contains 1970, the value of V19 is two and therefore, two is stored in X111. V11 is defined as X103+X111*K12 and determines the value of "T" in the forecast Equation (12)

$$F_{t+T} = (\bar{X}_t + T\bar{G}_t)\bar{S}_{(t+T-KL)}$$

where F_{t+T} is the forecast at time t for period T, $\bar{X}_t$ is the weighted demand at time t, T is the period in the future being studied, $\bar{G}_t$ is

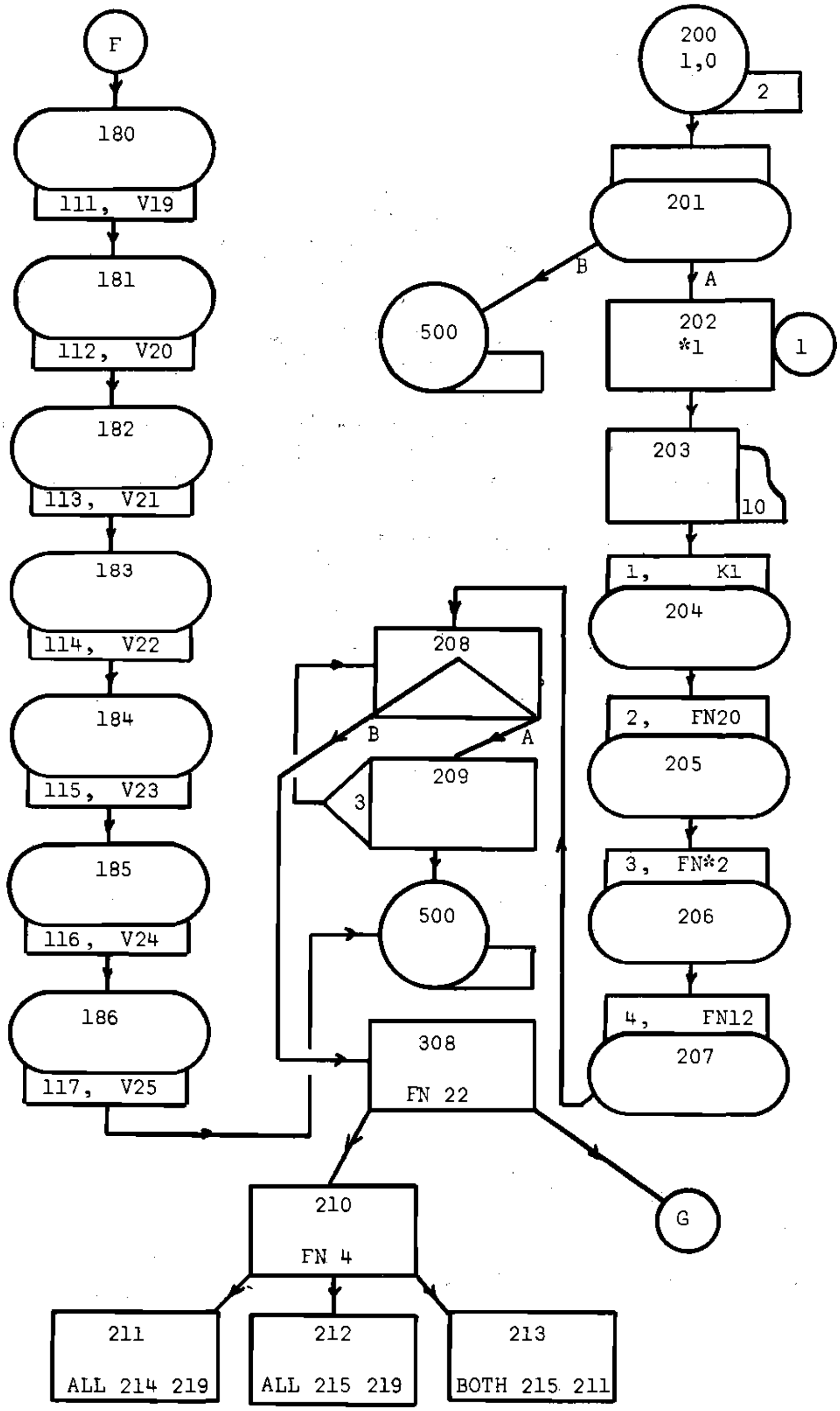


Figure 13. Accident Generation

the trend at time t and $\bar{S}_{t+T-KL}$ is the seasonal effect for the forecast period. An example of the use of this formula is included in Appendix C.

The value of that part of the equation in parentheses is calculated and stored in X112 and the value of F_{t+T} is stored in X113. Next, a factor is determined for the effect of time of day and weather. V22 combines the individual effects found in FN32 and FN34 and stores the information in X114. The daily rate is determined by dividing the monthly rate found in X113 by 30. This value becomes the entry in X115.

The adjusted daily rate stored in X116 is determined by multiplying the adjustment factor in X114 by the daily rate in X115 and dividing by a constant, ten, required by the limitations of the language to accept only integer values. Finally, the mean time between accidents is determined by dividing the total number of minutes in a day, 1440, by the adjusted accidents per day found in X116, thus giving a factor in minutes to be stored in X117. This value is updated every ten time units during the simulation to allow for changes caused by weather and time.

With the above information computed, the transactions representing accidents can commence. All of the previous steps were accomplished with no change in the clock time. The first transaction leaves block 200 at time two and is followed every time unit by a new transaction. Each transaction is assigned a value to its parameter one by V12 which takes the mean time between accidents as found in X117 and multiplies it by the exponential distribution function. Note that each time FUNCTION 30 is used it is immediately divided by 100 to eliminate the problem of decimal values previously mentioned.

Each transaction trys to enter block 202 which is a dummy store that holds a single transaction the length of time stipulated by parameter 1. Any backlog of transactions at block 201 is sent to block 500 and thus discarded. By this somewhat awkward method, those transactions reaching block 203 and beyond are properly spaced to simulate accidents. Block 203 provides a printout of time between accidents in Table 10 of the computer data.

A more conventional method, but one which failed to operate satisfactorily on Georgia Institute of Technology's Univac 1108 computer, would be to designate the time of the first transaction in the "X" field of the ORIGINATE block and then base future departure times on a function with V12 as the entry to the function.

In block 204 parameter one is redefined to designate the area in which an accident occurs. This also stands for the hospital which will receive the patient. If only one hospital is to be evaluated, this value is a constant, but if more than one hospital is to be evaluated, a function must be used to distribute the patients to the different hospitals in the proper proportions.

Block 205 assigns a value to parameter two of one, two, or three, standing for vehicle mode of preference.

1. Helicopter/Ambulance
2. Ambulance/Helicopter
3. Ambulance only.

If a helicopter is available it will handle all mode one calls, but ambulances are used as backup vehicles. The reverse is true for mode two calls. Mode three calls are only serviced by ambulances.

The number of vehicles required is determined by functions based on parameter two. The rationale for this is that the chances for multiple patients are different for different areas. For example, freeway accidents would be expected to require more than one emergency vehicle more often than residential accidents.

The distance to an accident site is determined from V28 which describes the area being studied. Each transaction has the distance value stored in parameter three as shown in block 207.

In most instances, blocks 208 and 209 serve no useful purpose; however, in the event that more than one vehicle is needed to service an accident, additional transactions are split off so that at block 308, each transaction represents the need for one vehicle.

Block 308 routes transactions to the vehicle sequence designated by FN22. Each accident area is given a sequence of ambulance locations which are called on to service calls. The procedure will be discussed for Area 1.

All requests for vehicles in Area 1 are sent to block 210. Where the transactions go from block 210 depends on the designated transportation mode stored in parameter two. All transactions designated mode one are sent to block 211, while mode two transactions are sent to block 212 and mode three transactions are sent to block 213.

When a transaction tries to enter block 214 from block 211, a test is made to see if a helicopter is available. If there is none, block 215 is tested to see if the primary ambulance point has an ambulance available. The procedure is continued through all possible ambulances until an available vehicle is found. The first block in the sequence which indicates an empty facility, representing a vehicle not in use allows the transaction to enter and continue its process. The same procedure is followed from block 212 except that the helicopter channel is not made available to the transaction.

Block 213 which handles the optional calls first checks block 215 to see if a primary ambulance is available. If none is available, the transaction goes to block 211 and tries to enter each COMPARE block from 214 to 219 until it finds an available facility (Figure 14).

The procedure is the same for adding additional accident areas. For each new hospital the researcher wishes to add to the system an additional set of blocks corresponding to blocks 310 through 319 must be added (Figure 15). The sequence of facilities to be tested must be changed to correspond to the new area. An example of this is given by the rearranging of the VARIABLES in blocks 314 through 319 compared to the similar 200 level blocks. Note that the facilities denoted by V46 were the first ambulance choice for Area 1 but are the last choice for Area 2. Location would be the major reason for this occurrence.

Vehicle Assignment and Service

When a transaction leaves block 210 (or 310, 410, etc.) it enters a COMPARE block which signifies an available facility. The location of the facility (or vehicle) in the system is assigned to the transaction's

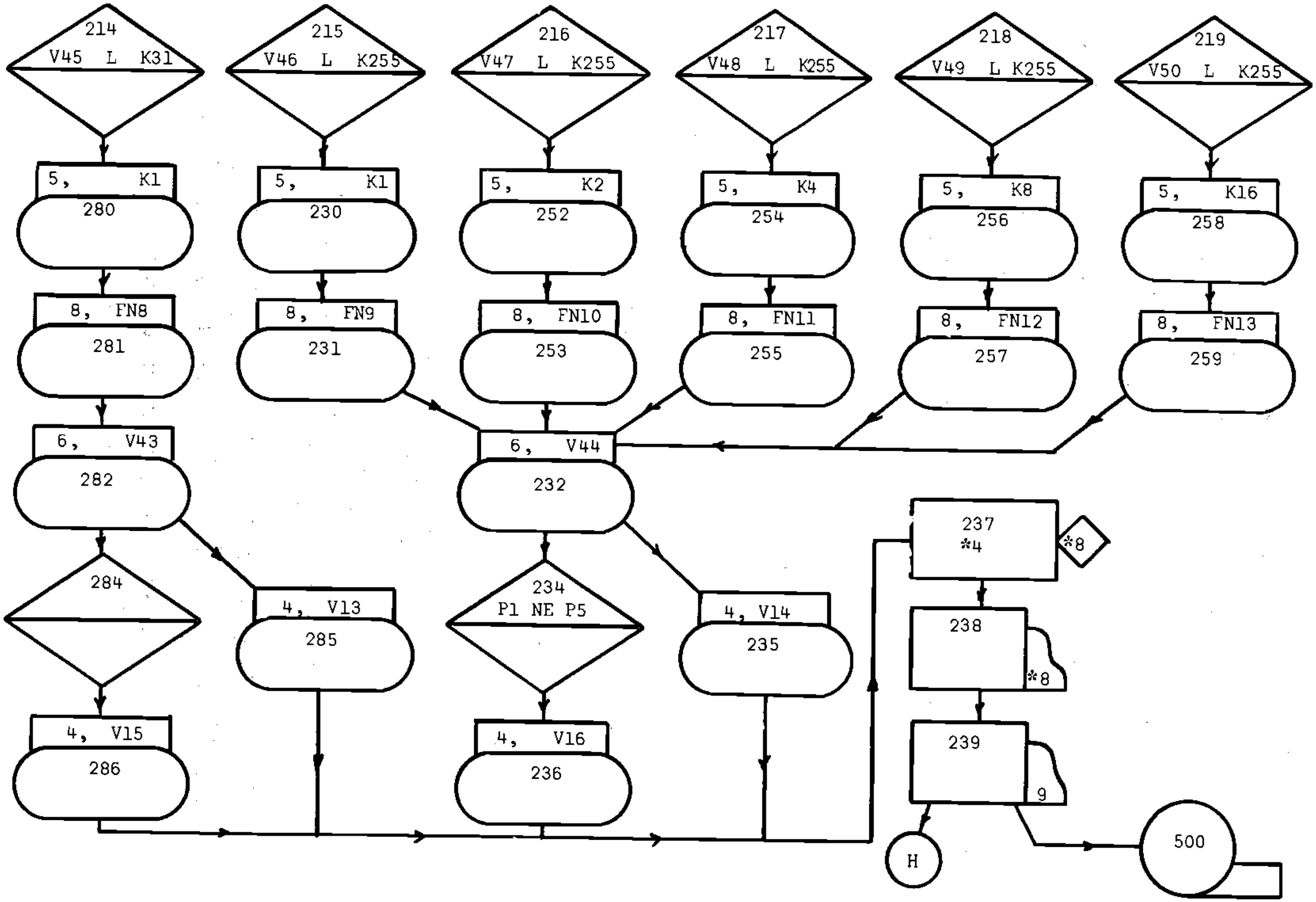


Figure 14. Vehicle Assignment and Service

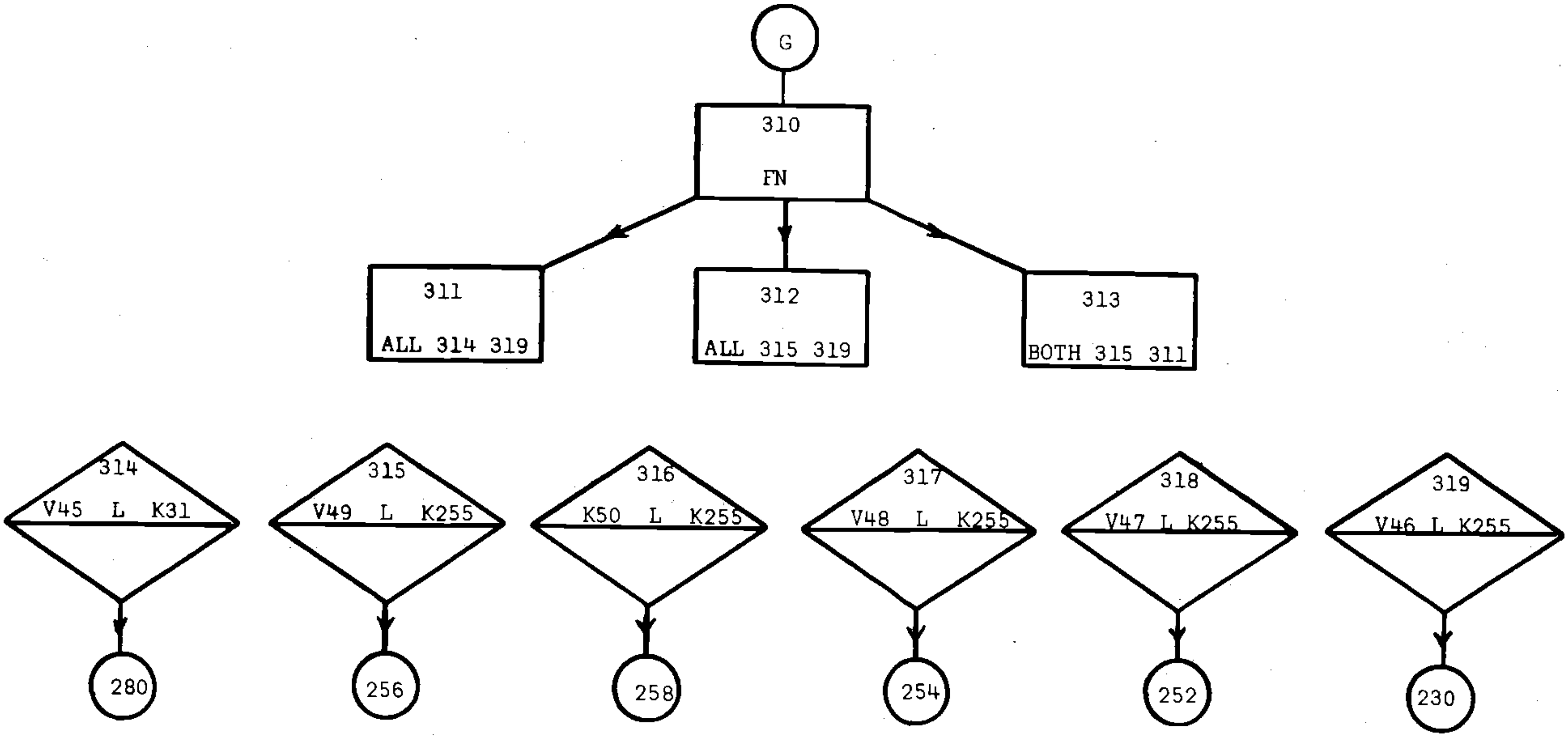


Figure 15. Second Hospital Vehicle Assignment

parameter five. The facility number is assigned to parameter eight and the effect of weather and time of day on service time is assigned to parameter six (Figure 14). All ambulances use block 232 since the weather and time factor is the same for all surface vehicles.

At blocks 234 or 284, parameters one and five of each transaction are compared. If the values of the two parameters are equal, the vehicle is required to go to the accident site and then return to its starting point. The next block is then either 235 or 285 depending on whether it is an ambulance or helicopter. If the parameters are not equal, the vehicle is required to travel to the accident site and then continue to the point designated in parameter one. For this case the transactions enter the appropriate COMPARE block and pass on to either block 236 or 286. Parameter four is assigned the service time based on the appropriate variable. The service times are required in the HOLD block, 237.

All vehicles are represented by block 237 by indirect specification. Parameter eight of each transaction indicates which facility or vehicle is to be held and parameter four indicates how long. The service time for each transaction is tabulated in block 238 upon the transaction's release from block 237, the composite of all transaction service times is collected in block 238 and printed in Table 9.

Maintenance

All servicing and maintenance on surface vehicles are considered to be performed during the period when these vehicles are not scheduled for duty. The helicopters, however, require periodic maintenance of considerable duration and since there are only a few in the system, the effect must be taken into account.

A transaction leaving block 239 (Figure 14) first tries to enter block 243 (Figure 16). Only those transactions serviced by helicopters are allowed to enter; all other transactions are terminated at block 500. Parameter eight is then increased by 200 to indicate a new set of SAVEX locations, 281 through 285. These locations are used to store the cumulative flying hours until the time of major overhaul of the corresponding helicopter at which time the SAVEX location reverts to zero and starts counting again with the next transaction service time assigned to its representative helicopter by parameter four.

Once it has been established that maintenance is due, parameter eight is reduced by 200, thus reverting back to its previous value. It is then used in block 250 to designate the facility to be held for maintenance. The time is again determined by parameter four based on its new service time value obtained in block 249.

No provision is made for the time required for a vehicle to return to its home station from another area on the basis that a helicopter would be ready for flight after making one call and thus could continue on to a second accident site with little difference in time. An ambulance could be used to service any calls on its route to its home station, thus minimizing any effect its dislocation might cause on the system.

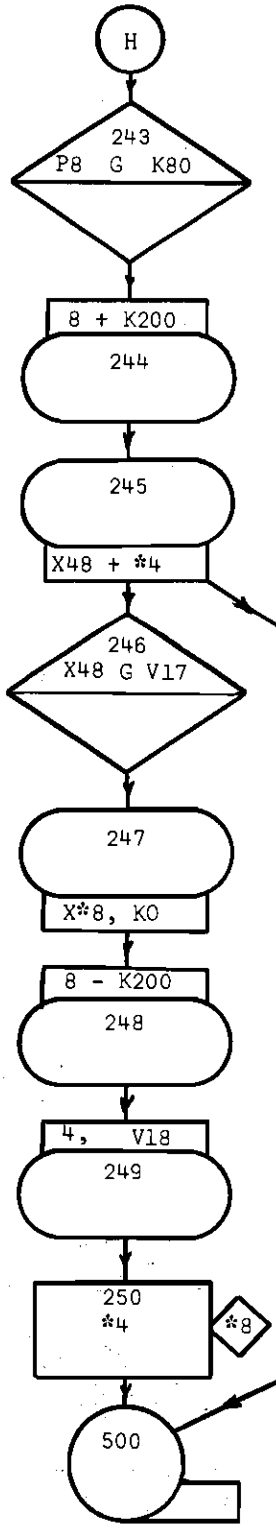


Figure 16. Maintenance Section

LOC	NAME		X	Y	Z	SEL	NBA	NBB	MEAN	MOD	REMARKS	E
	JOB		070157255221									

****

1	FUNCTION		RN1	D2							# VEH. MODE 1
.99	1	1	2								
2	FUNCTION		RN1	D2							# VEH. MODE 2
.995	1	1	2								
3	FUNCTION		RN1	D2							# VEH. MODE 3
.9	1	1	1								
4	FUNCTION		P2	D3							VEH. MODE PATH
1	211	2	212	3	213						
5	FUNCTION		X103	D12							S[T]
1	91	2	124	3	105	4	108	5	105	6	113
7	97	8	92	9	96	10	90	11	91	12	87
8	FUNCTION		V45	D5							HC ASSIGNMENT
15	81	23	82	27	83	29	84	30	85		
9	FUNCTION		V46	D7							#1 ASSIGNMENT
63	1	95	2	111	3	119	4	123	5	125	6
126	7										
10	FUNCTION		V47	D7							#2 ASSIGNMENT
63	11	95	12	111	13	119	14	123	15	125	16
126	17										
11	FUNCTION		V48	D7							#3 ASSIGNMENT
63	21	95	22	111	23	119	24	123	25	125	26
126	27										
12	FUNCTION		V49	D7							#4 ASSIGNMENT
63	31	95	32	111	33	119	34	123	35	125	36
126	37										
13	FUNCTION		V50	D7							#5 ASSIGNMENT
63	41	95	42	111	43	119	44	123	45	125	46
126	47										
14	FUNCTION		V5	D13							#1 AMB SERVICE
60	3	90	4	180	5	420	6	510	5	570	4
840	3	990	2	1020	1	1080	2	1110	3	1350	2
1440	3										
15	FUNCTION		V5	D3							#2 AMB SERVICE
420	5	1380	2	1440	5						
16	FUNCTION		V5	D3							#3 AMB SERVICE
420	5	1380	2	1440	5						
17	FUNCTION		V5	D3							#4 AMB SERVICE
420	5	1380	2	1440	5						
18	FUNCTION		V5	D3							#5 AMB SERVICE
420	5	1380	2	1440	5						
19	FUNCTION		X105	D9							WEA DURATION
0	60	1	60	2	120	3	180	4	180	5	180
6	120	7	240	8	1440						
20	FUNCTION		X105	D9							WEA EFF ON ACC
0	75	1	90	2	100	3	120	4	120	5	105
6	125	7	100	8	90						
22	FUNCTION		RN1	D2							ACC AREA DIST-
.5	210	1	210								
23	FUNCTION		P2	D3							VEH CHOICE
1	311	2	312	3	313						
24	FUNCTION		X105	D9							WEA EFF ON HC
0	20	1	20	2	30	3	5	4	0	5	0

```
6     0     7     0     8     0
 25   FUNCTION    V5    D5                                                TIME EFF ON HC
360   2     540   0     960   0     1140  0     1440  0
 26   FUNCTION    X105  D9                                                WEA EFF ON AM
0     30    1     20    2     0     3     10    4     10    5     5
6     5     7     0     8     0
 27   FUNCTION    V5    D24                                               TIME EFF ON AC
60    96    120   63    180   40    240   31    300   28    360   21
420   30    480   71    540   92    600   119   660   119   720   110
780   147   840   147   900   142   960   119   1020  119   1080  138
1140  132   1200  157   1260  129   1320  114   1380  137   1440  102
 28   FUNCTION    RN1   D3                                                VEHICLE MODE
.3    1     .7    2     1     3
 29   FUNCTION    V5    D7                                                TIME EFF AMB
360   0     480   15    600   20    720   15    900   20    1140  25
1440  15
 30   FUNCTION    RN1   C24                                               EXP DISTRIB
0     0     .1    14    .2    22    .3    35    .4    51    .5    69
.6    91    .7    120   .75   138   .8    160   .84   183   .88   212
.9    230   .92   252   .94   281   .95   299   .96   320   .97   350
.98   390   .99   460   .995  530   .998  620   .999  700   1     800
 31   FUNCTION    RN1   C3                                                DIST. P1
0     2     .5    6     1     10
 32   FUNCTION    RN1   C2                                                DIST. P1=P5
0     1     1     20
*******WEATHER CONDITION TYPES*******
*0 - HEAVY FOG OR DUST          *4 - ICE ON PAVEMENT             *8 - CLEAR
*1 - HEAVY SNOW OR RAIN         *5 - LIGHT SNOW
*2 - HIGH WINDS                 *6 - LIGHT RAIN
*3 - LIGHT SNOW AND ICE         *7 - CLEAR AND COLD(BELOW 40F)
* FUNCTION 51 THRU 62 REQUIRES THE PROBABILITY DISTRIBUTION OF DIFFERENT
*TYPES OF WEATHER.
 51   FUNCTION    RN1   D9                                                JAN
.0833 0     .125  1     .1667 2     .1875 3     .2083 4     .2292 5
.4375 6     .6667 7     1     8
 52   FUNCTION    RN1   D9                                                FEB
.0682 0     .1137 1     .1591 2     .1818 3     .2045 4     .2273 5
.4318 6     .6364 7     1     8
 53   FUNCTION    RN1   D6                                                MAR
.0513 0     .1282 1     .1795 2     .4872 6     .5128 7     1     8
 54   FUNCTION    RN1   D6                                                APR
.0303 0     .0909 1     .1212 2     .3636 6     .3939 7     1     8
 55   FUNCTION    RN1   D5                                                MAY
.0303 0     .0606 1     .0909 2     .3333 6     1     8
 56   FUNCTION    RN1   D5                                                JUN
.0116 0     .0606 1     .0909 2     .3636 6     1     8
 57   FUNCTION    RN1   D5                                                JUL
.0294 0     .0882 1     .1176 2     .4117 6     1     8
 58   FUNCTION    RN1   D5                                                AUG
.0294 0     .0588 1     .0882 2     .3823 6     1     8
 59   FUNCTION    RN1   D5                                                SEP
.0313 0     .0625 1     .0937 2     .3125 6     1     8
 60   FUNCTION    RN1   D5                                                OCT
.0313 0     .0625 1     .0937 2     .2812 6     1     8
 61   FUNCTION    RN1   D5                                                NOV
.0571 0     .0857 1     .1143 2     .3143 6     1     8
 62   FUNCTION    RN1   D9                                                DEC
.0851 0     .1277 1     .1702 2     .1915 3     .2128 4     .2340 5
```

```
.4255 6       .6383 7       1       8
***************************************************************************
  1     VARIABLE     K50+X103                                       WEA FN NUMBER
  2     VARIABLE     FN19*FN30/K100                                 WEA DURATION
  3     VARIABLE     X106+C1                                        WEA END TIME
  5     VARIABLE     C1/K1440                                       C1 CONVERSION
  6     VARIABLE     K7-FN14                                        #1 SCHEDULE AM
  7     VARIABLE     K7-FN15                                        #2 SCHEDULE AM
  8     VARIABLE     K7                                             #3 SCHEDULE AM
  9     VARIABLE     K7                                             #4 SCHEDULE AM
 10     VARIABLE     K7                                             #5 SCHEDULE AM
 11     VARIABLE     X103+K12*V19                                   'T' IN MONTHS
 12     VARIABLE     X117*FN30/K100                                 T. B. CALLS
 13     VARIABLE     P4*K2/K3+FN32+P4*P6*FN30/K1500                 HC SER. TIME
 14     VARIABLE     P4*K3/K2+FN32+P4*P6*FN30/K666                  AM SER. TIME
 15     VARIABLE     FN31*K2/K3+FN32+FN31*V43*FN30/K1500            HC TIME PT.2
 16     VARIABLE     FN31*K4/K2+FN32+FN31*V44*FN30/K500             AM TIME PT. 2
 17     VARIABLE     K1100*K60                                      MOH TIME FOR H
 18     VARIABLE     K4320+K4320*FN30/K100                          MOH SERV. TIME
 19     VARIABLE     X104-K1967                                 YEARS INTO FUTURE T
 20     VARIABLE     K1593+K25*V11                                  X+G*T
 21     VARIABLE     X112*FN5/K100                                  ACC. FORECAST
 22     VARIABLE     FN20+FN27                                      WEA+TIME ACC
 23     VARIABLE     X113/K30                                       DAILY ACC RATE
 24     VARIABLE     X114*X115/K200                                 ADJ ACC RATE
 25     VARIABLE     K1440/X116                                     BETWEEN ACC
 26     VARIABLE     X*8+P4                                         TIME SINCE MOH
 27     VARIABLE     P1+P5                                          DIST. FACTOR
 28     VARIABLE     K3+K3*FN30/K100                                DIST. HOSP. #1
 43     VARIABLE     FN24+FN25                                      WEA + TIME HC
 44     VARIABLE     FN26+FN29                                      WEA + TIME AM
 45     VARIABLE     K16*F81+K8*F82+K4*F83+K2*F84+F85               HC CHECK
 46     VARIABLE     K64*F1+K32*F2+K16*F3+K8*F4+K4*F5+K2*F6+F7      #1 AM CHECK
 47     VARIABLE     K64*F11+K32*F12+K16*F13+K8*F14+K4*F15+K2*F16+F17 #2 AM CHECK
 48     VARIABLE     K64*F21+K32*F22+K16*F23+K8*F24+K4*F25+K2*F26+F27 #3 AM CHECK
 49     VARIABLE     K64*F31+K32*F32+K16*F33+K8*F34+K4*F35+K2*F36+F37 #4 AM CHECK
 50     VARIABLE     K64*F41+K32*F42+K16*F43+K8*F44+K4*F45+K2*F46+F47 #5 AM CHECK
**************************************************************************8
 100    ORIGINATE    10            6               101            10
 101    SAVEX        100+    K10          BOTH     102     103          MIN. COUNTER
 102    COMPARE      X100    L     K60             114
 103    SAVEX        100     K0                    104                  COUNTER RESET
 104    SAVEX        101+    K1           BOTH     105     106          HOUR COUNTER
 105    COMPARE      X101    L     K24             114
 106    SAVEX        101     K0                    107                  COUNTER RESET
 107    SAVEX        102+    K1           BOTH     108     109          DAY COUNTER
 108    COMPARE      X102    L     K31             114
 109    SAVEX        102     K1                    110                  COUNTER RESET
 110    SAVEX        103+    K1           BOTH     111     112          MON. COUNT59
 111    COMPARE      X103    L     K13             114
 112    SAVEX        103     K1                    113                  COUNTER RESET
 113    SAVEX        104+    K1                    114                  YEAR COUNTER
 114    ASSIGN       1       V1           BOTH     115     122          WEA FN NUMBER
 115    COMPARE      X107    L     C1              116
 116    SAVEX        105     FN*1                  117                  WEATHER TYPE
 117    SAVEX        106     V2                    118                  WEA DURATION
 118    SAVEX        107     V3                    119                  WEA END TIME
 119    PRINT        100     107          BOTH     120     122          PRINT BAD WEA
```

120	COMPARE	X105	L	K3		121			
121	ASSIGN	3	X107			124			WEA SCH TIME
122	ASSIGN	3	K10			123			NORMAL SCHED-
123	ASSIGN	3+	C1			125			ULE TIME.
124	ASSIGN	4	K5			126			# HCOPTERS OUT
125	ASSIGN	4	K5			126			# HCOPTERS OUT
126	SPLIT					133	127		
127	ADVANCE					128			
128	COMPARE	V45	L	K31		129			
129	ASSIGN	8	FN8		BOTH	130	500		ASGN FACILITY
130	COMPARE	P3	G	C1		131			
131	ASSIGN	3-	C1			132			FAC HOLD TIME
132	HOLD	*8				500		*3	SECHEULING
133	LOOP	4				126	179		HCOPTER COUNT
134	ASSIGN	3	K10			135			RESET SCHED-
135	ASSIGN	3+	C1			136			ULING TIME.
136	ASSIGN	4	V6			137			#1 AMBS OUT
137	SPLIT					141	138		
138	ADVANCE					139			
139	COMPARE	V46	L	K255		140			
140	ASSIGN	8	FN9		BOTH	130	500		ASGN FACILITY
141	LOOP	4				137	142		#1 AMB COUNTER
142	ASSIGN	4	V7			143			#2 AMBS OUT
143	SPLIT					147	144		
144	ADVANCE					145			
145	COMPARE	V47	L	K255		146			
146	ASSIGN	8	FN10		BOTH	130	500		ASGN FACILITY
147	LOOP	4				143	148		#2 AMB COUNTER
148	ASSIGN	4	V8			149			#3 AMBS OUT
149	SPLIT					153	150		
150	ADVANCE					151			
151	COMPARE	V48	L	K255		152			
152	ASSIGN	8	FN11		BOTH	130	500		ASGN FACILITY
153	LOOP	4				149	154		#3 AMB COUNTER
154	ASSIGN	4	V9			155			#4 AMBS OUT
155	SPLIT					159	156		
156	ADVANCE					157			
157	COMPARE	V49	L	K255		158			
158	ASSIGN	8	FN12		BOTH	130	500		ASGN FACILITY
159	LOOP	4				155	160		#4 AMB COUNTER
160	ASSIGN	4	V10			161			#5 AMBS OUT
162	ADVANCE					163			
163	COMPARE	V50	L	K255		164			
161	SPLIT					165	162		
164	ASSIGN	8	FN13		BOTH	130	500		ASGN FACILITY
165	LOOP	4				161	500		#5 AMB COUNTER
170	ORIGINATE	1		6		171		21600	
171	SAVEX	101	K0			172			* INITIALIZE
172	SAVEX	102	K1		BOTH	175	173		* TIME
173	SAVEX	103	K10			174			* KEEPING
174	SAVEX	104	K1969			114			* * * * * * *
175	COMPARE	X103	G	K0		176			
176	SAVEX	103+	K3			177			
177	SAVEX	104	K1969			114			ADDITIONAL YR.
179	SPLIT					134	180		
180	SAVEX	111	V19			181			T
181	SAVEX	112	V20			182			(X+GT)
182	SAVEX	113	V21			183			FORECAST

```
 183  SAVEX       114   V22                 184                     (WEA+TIME)
 184  SAVEX       115   V23                 185                     DAILY ACC RATE
 185  SAVEX       116   V24                 186                     ADJ RATE
 186  SAVEX       117   V25                 500                     TIME BET ACC
*****************************************************************************
 200  ORIGINATE   2                         201         1
 201  ASSIGN      1     V12          BOTH   202   500               TIME NEXT ACC.
 202  STORE       1                         203         *1          ADVANCE CLOCK
 1    CAPACITY    1
 203  TABULATE    10                        204                     TAB ACC TIMES
 204  ASSIGN      1     K1                  205                     # ACC AREA
 205  ASSIGN      2     FN28                206                     VEHICLE MODE
 206  ASSIGN      3     FN*2                207                     # VEH. RQD.
 207  ASSIGN      4     V28                 208                     DISTANCE
 208  SPLIT                                 209   210               VEH DISPENSER
 209  LOOP        3                         308   500               VEH. COUNTER
 210  ADVANCE                        FN     4                       **************
 211  ADVANCE                        ALL    214   219               * VEHICLE
 212  ADVANCE                        ALL    215   219               * MARSHALING
 213  ADVANCE                        BOTH   215   211               * FOR
 214  COMPARE     V45   L      K31          280                     * AREA
 215  COMPARE     V46   L      K255         230                     * #1
 216  COMPARE     V47   L      K255         252                     *
 217  COMPARE     V48   L      K255         254                     *
 218  COMPARE     V49   L      K255         256                     *
 219  COMPARE     V50   L      K255         258                      * * * * * * *
 230  ASSIGN      5     K1                  231                     #1 VEHICLE PT.
 231  ASSIGN      8     FN9                 232                     ASGN FACILITY
 232  ASSIGN      6     V44          BOTH   234   235               TIME+ WEA EFF.
 234  COMPARE     P1    NE     P5           236
 235  ASSIGN      2     V14                 237                     LOCAL S. TIME
 236  ASSIGN      2     V16                 237                     OTHER S. TIME
 237  HOLD        *8                        238         *2          ALL FACILITIES
 238  TABULATE    *8                        239                     FAC. STATS.
 239  TABULATE    9                  BOTH   243   500               COMPOSITE STAT
 243  COMPARE     P8    G      K80          244
 244  ASSIGN      8+    K200                245                     P8=(281,285)
 245  SAVEX       *8    V26          BOTH   246   500               TIME SINCE MOH
 246  COMPARE     X*8   G      V17          247
 247  SAVEX       *8    K0                  248                     RESET ENGINE
 248  ASSIGN      8-    K200                249
 249  ASSIGN      4     V37                 250                     MAINT. TIME
 250  HOLD        *8                        501         *4          HCOPTER MAINT.
 252  ASSIGN      5     K2                  253                     #2 VEHICLE PT.
 253  ASSIGN      8     FN10                232                     ASGN FACILITY
 254  ASSIGN      5     K4                  255                     #3 VEHICLE PT.
 255  ASSIGN      8     FN11                232                     ASGN FACILITY
 256  ASSIGN      5     K8                  257                     #4 VEHICLE PT.
 257  ASSIGN      8     FN12                232                     ASGN FACILITY
 258  ASSIGN      5     K16                 259                     #5 VEHICLE PT.
 259  ASSIGN      8     FN13                232                     ASGN FACILITY
 280  ASSIGN      5     K1                  281                     #1 VEHICLE PT.
 281  ASSIGN      8     FN8                 282                     ASGN FACILITY
 282  ASSIGN      6     V43          BOTH   284   285               TIME+WEA EFF
 284  COMPARE     P1    NE     P5           286
 285  ASSIGN      2     V13                 237                     LOCAL S. TIME
 286  ASSIGN      2     V15                 237                     OTHER S. TIME
 308  ADVANCE                        FN     22
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 310  ADVANCE                      FN    23                      **************
 311  ADVANCE                      ALL   314    319              * VEHICLE
 312  ADVANCE                      ALL   315    319              * MARSHALING
 313  ADVANCE                      BOTH  315    311              * FOR
 314  COMPARE     V45   L    K31         280                      * AREA
 315  COMPARE     V49   L    K255        256                      * #2
 316  COMPARE     V50   L    K255        258                      *
 317  COMPARE     V48   L    K255        254                      *
 318  COMPARE     V47   L    K255        252                      *
 319  COMPARE     V46   L    K255        230                      **************
 500  TERMINATE
501   TERMINATE
*****************************************************************************
 1    TABLE       P2    5    5     100
 2    TABLE       P2    5    5     100
 3    TABLE       P2    5    5     100
 4    TABLE       P2    5    5     100
 5    TABLE       P2    5    5     100
 6    TABLE       P2    5    5     100
 7    TABLE       P2    5    5     100
 8    TABLE       P2    5    5     100
 9    TABLE       P2    5    5     100
 10   TABLE       P1    0    5     100
 81   TABLE       P2    5    5     100
 82   TABLE       P2    5    5     100
 83   TABLE       P2    5    5     100
 84   TABLE       P2    5    5     100
 85   TABLE       P2    5    5     100
      START                  21600

SAVEX  NR,     VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE
        100        0   101            0   102            1   103           10   104         1969
        105        8   106          331   107          332   108            0   109            0

SAVEX  NR,     VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE
        100       40   101            5   102            1   103           10   104         1969
        105        8   106         7070   107         7410   108            0   109            0

SAVEX  NR,     VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE
        100       40   101            3   102            6   103           10   104         1969
        105        8   106          648   107         8068   108            0   109            0

SAVEX  NR,     VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE
        100       30   101           14   102            6   103           10   104         1969
        105        8   106         6739   107        14809   108            0   109            0

SAVEX  NR,     VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE
        100       50   101            6   102           11   103           10   104         1969
        105        8   106          172   107        14982   108            0   109            0

SAVEX  NR,     VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE
        100       50   101            9   102           11   103           10   104         1969
        105        8   106          489   107        15479   108            0   109            0

SAVEX  NR,     VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE    NR,       VALUE
        100        0   101           18   102           11   103           10   104         1969
        105        8   106         1584   107        17064   108            0   109            0
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APPENDIX C

FORECASTING TECHNIQUE AND EXAMPLE

APPENDIX C

FORECASTING TECHNIQUE AND EXAMPLES

The trend in service calls could be taken as the difference between consecutive periods,

$$\bar{G}_t = \bar{X}_t - \bar{X}_{t-1}$$

but for forecasting, it is more relevant to consider an estimate of the average trend over all past data, exponentially averaged (12). It is assumed that the average trend at period t is a normalized linear combination of the trend for that period and the average trend for the past period.

$$\bar{G}_t = \gamma G_t + (1-\gamma)\bar{G}_{t-1} \quad \text{for } 0 \leq \gamma \leq 1$$

As γ approaches 1 the effect of the past trend decreases and more weight is given to the current trend.

The seasonal effect on the call rate is the deviation from the average for a particular period.

$$\bar{S}_t = D_t/\bar{X}_t$$

where D_t is a data value for time t. If L is the number of periods in a cycle and the average seasonal factor is considered to be a normalized combination of the present factor and the average factor for the past period, then

$$\bar{S}_t = \beta(D_t/\bar{X}_t) + (1-\beta)\bar{S}_{t-1}$$

As β approaches one the seasonal factor becomes more sensitive to fluctuations in changes between periods.

The exponentially weighted average becomes

$$\bar{X} = (\alpha D_t/\bar{S}_{t-L}) + (1-\alpha)(\bar{X}_{t-1}+\bar{G}_{t-1}) \quad \text{for} \quad 0\leq\alpha\leq 1$$

The forecast formula can be written

$$F_{t+T} = (\bar{X}_t+T\bar{G}_t)\bar{S}_{(t+T-L)} \quad \text{for} \quad T\leq L$$

or

$$F_{t+T} = (\bar{X}_t+T\bar{G}_t)\bar{S}_{(t+T-KL)} \quad \text{for} \quad (K-1)L\leq T\leq KL$$

thus taking into account forecasts of more than the number of periods in one cycle. The value of K is the integer value of T/L.

Computational Sequence

Initial conditions for the forecast computational sequence can be obtained as follows.

a. For $\bar{X}_0$, use the average of all the available data.

b. For $\bar{G}_0$, let the average of the data for the first L items of historical data equal V_1, and the average of the data for the last L items of data for the last L items of data equal V_2. Then

$$\bar{G}_0 = (V_2 - V_1)/K$$

where K is the number of periods between the first L items of data and the last L items of data.

c. For $\bar{S}_{1-L}, \bar{S}_{2-L}, \cdots, \bar{S}_0$ consider only initial data in multiples of L. (For example, if ten items of data are available, and L 4, then only consider the first eight items of data.) Let V_i be the average for the ith multiple of the Lth year; then, for each period t in the ith year compute:

$$K_t = D_t/V_i - \frac{(L+1)}{2} - t\ \bar{G}_0 \qquad t=1,2,\cdots,L_i$$

for each year i being considered. The values of K_t are then averaged over all i, yielding a set of $\bar{K}_t$. These are normalized as follows to yield the initial estimates.

$$\bar{S}_{t-L} = K_t L / \sum_{t=1}^{L} K_t \qquad \text{for } t=1,L$$

For any period t for which historical data is available:

1. Compute

$$\bar{X}_t = \alpha \frac{D_t}{\bar{S}_{t-1}} + (1-\alpha)(\bar{X}_{t-1} + \bar{G}_{t-1})$$

2. Compute

$$\bar{G}_t = \gamma(\bar{X}_t - \bar{X}_{t-1}) + (1-\gamma)\bar{G}_{t-1}$$

3. Compute

$$S_t = \beta \frac{D_t}{\bar{X}_t} + (1-\beta)\bar{S}_{t-1}$$

4. Set t = t+1 and go back to step one.

Example of Forecasting Technique

Table 5. Calls Answered by Grady Hospital

Month	Year 1966	1967	1968
JAN	1056	1302	1785
FEB	1002	1271	1582
MAR	1217	1440	1685
APR	1156	1468	1706
MAY	1295	1482	1948
JUN	1231	1401	1785
JUL	1342	1641	1839
AUG	1382	1761	1976
SEP	1287	1697	1890
OCT	1402	1772	2153
NOV	1365	1752	2154
DEC	1441	1822	1891
TOTAL	15176	18810	22394

Using the first two years (the third year's data will be used to show updating procedure):

a. $\bar{X}_0 = (1/n) \sum_{t=1}^{n} D_t = 33{,}986/24 = 1{,}416$

b. $V_1 = (15176/12) = 1264.67$

$V_2 = (18810/12) = 1567.50$

$\bar{G}_0 = (V_2 - V_1)/K = (1567.50-1264.67)/12 = 25.2$

c. $K_t = D_t/[V_i - (\frac{L-1}{2} - t)\bar{G}_0]$ for $t=1,2,\cdots,12$; $L=12$; $i=1,2$

For values of K_t see Table 5.

Table 6. Values of K_t and S_{t-L}

i = 1

t	D_t	V_i	$\frac{L-1}{2} - t$	$\bar{G}_0$	K_{ti}
1	1056	1265	5.5	138.5	.934
2	1002		4.5	113.3	.870
3	1217		3.5	88.5	1.034
4	1156		2.5	63.0	.961
5	1295		1.5	37.8	1.056
6	1231		.5	12.6	.984
7	1342		-.5	-12.6	1.051
8	1382		-1.5	-37.8	1.060
9	1287		-2.5	-63.0	.970
10	1402		-3.5	-88.5	1.036
11	1365		-4.5	-113.3	.993
12	1441		-5.5	-138.5	1.028

i = 2

t	D_t	V_i	$\frac{L-1}{2} - t$	$\bar{G}_0$	K_{ti}	$\frac{1}{2} K_{ti}$	$\bar{S}_{t-L}$
1	1302	1568	5.5	138.5	.913	.924	.927
2	1271		4.5	113.3	.875	.873	.876
3	1440		3.5	88.5	.975	1.004	1.007
4	1468		2.5	63.0	.975	.968	.970
5	1482		1.5	37.8	.970	1.013	1.058
6	1401		.5	12.6	.902	.943	.986
7	1641		-.5	-12.6	1.039	1.045	1.055
8	1761		-1.5	-37.8	1.097	1.073	1.062
9	1697		-2.5	-63.0	1.040	1.005	.973
10	1772		-3.5	-88.5	1.070	1.056	1.039
11	1752		-4.5	-113.3	1.041	1.017	.996
12	1822		-5.5	-138.5	1.069	1.048	1.031
						11.966	

With these initialization steps complete, all data values must be processed as follows:

$$\bar{X}_1 = (\alpha D_1/\bar{S}_{1-L}) + (1-\alpha)(\bar{X}_0+\bar{G}_0) \qquad \text{for } \alpha=.7$$
$$= (.7(1056)/.927) + (.3)(1416+25.2)$$
$$= 796 + 432$$
$$= 1228$$

$$\bar{G}_1 = \gamma(\bar{X}_1-\bar{X}_0) + (1-\gamma)\bar{G}_0 \qquad \text{for } \gamma=.2$$
$$= .2(1228-1416) + .8(25.2)$$
$$= .2(-188) + .8(25.2)$$
$$= -17.4$$

$$\bar{S}_1 = (\beta D_1/\bar{X}_1) + (1-\beta)\bar{S}_{1-L} \qquad \text{for } \beta=.7$$
$$= (.7(1057)/1228) + (.3)(.927)$$
$$= .603 + .278$$
$$= .881$$

The same procedure is repeated for all data values which yield the entries in Table 6.

As an example of forecasting, assume it is desired to predict the number of accidents in April, 1969. Since April is the fourth month, t=36, T=4, and S_{t+T-L} = .985.

$$F_{40} = (\bar{X}_t+TG_t)S_{t+T-L} = (1874 + 4(-4.7)).985 = 1846$$

The value of $\bar{G}_{36}$ is not representative of the average $\bar{G}$ value. An unusually light service rate caused the reversal in slope.

Table 7. Values of $\bar{X}_t$, $\bar{G}_t$ and S_{t-L}

1966				1967				1968			
t	$\bar{X}_t$	$\bar{G}_t$	$\bar{S}_{t-L}$	t	$\bar{X}_t$	$\bar{G}_t$	$\bar{S}_{t-L}$	t	$\bar{X}_t$	$\bar{G}_t$	$\bar{S}_{t-L}$
1	1228	-17.4	.881	13	1459	28.1	.890	25	1622	.4	1.038
2	1164	-30.9	.866	14	1475	25.7	.863	26	1773	30.6	.884
3	1195	-18.5	1.014	15	1443	14.2	1.003	27	1717	13.3	.986
4	1187	-16.4	.979	16	1486	20.0	.984	28	1729	13.0	.985
5	1209	-8.7	1.067	17	1426	8.0	1.055	29	1813	27.2	1.062
6	1234	-1.96	.992	18	1420	5.2	.988	30	1816	22.4	.983
7	1261	3.8	1.060	19	1588	37.8	1.040	31	1789	12.5	1.031
8	1291	9.0	1.067	20	1645	41.6	1.069	32	1835	19.2	1.072
9	1316	12.2	.976	21	1724	49.1	.979	33	1907	29.8	.987
10	1342	15.0	1.043	22	1721	38.7	1.033	34	2038	50.0	1.050
11	1366	16.8	.999	23	1755	37.8	.997	35	2136	59.6	1.004
12	1393	18.6	1.113	24	1683	15.8	1.090	36	1874	-4.7	1.033

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